GEOLOGY OF BAT CAVE QUADRANGLE, COMAL

AND BEXAR COUNTIES, TEXAS

APPROVED:

Keith Young

GEOLOGY OF BAT CAVE QUADRANGLE, COMAL AND BEXAR COUNTIES, TEXAS

by

JOHN HARTNELL NEWCOMB, B.S.

THESIS

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F R O N T I S P I E C E

The entrance to Bracken Bat Cave.

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John Hartnell Newcomb

A B S T R A C T

Bat Cave quadrangle lies on the maturely dissected eastern margin of the Edwards Plateau. Sinkholes, caves, and other karst features are common throughout the uplands.

Approximately 1,050 feet of dominantly carbonate rock comprises the ten Cretaceous formations cropping out in the quadrangle. The upper part of the Glen Rose Formation, the Walnut, Kainer, and Person Formations, the Georgetown Limestone, Del Rio Clay, Buda Limestone, Eagle Ford Shale, Austin Limestone, and Taylor Clay are exposed. The oldest and youngest rocks crop out in the northwestern and southeastern corners, respectively.

Five major, downthrown to the coast, high angle, normal faults of the Balcones fault system pass through the quadrangle. Together with 86 minor antithetic, synthetic, and cross faults, they produce 1,200 feet of stratigraphic displacement from northwest to southeast. Major faults trend between N. 40° E. and N. 60° E. Minor faults have more variable orientations, but tend to strike either east-west or N. 40° E. to N. 60° E.

The Upper Member of the Glen Rose Formation supplies

small amounts of fair to poor quality water to wells in the northern half of the quadrangle. The Kainer and Person Formations, which yield large amounts of good quality calcium bicarbonate water, are the principal aquifers in the southern half.

CONTENTS

Page

TABLES

ILLUSTRATIONS

INTRODUCTION

<u>Location</u>.--Bat Cave quadrangle includes 65 square miles of south-central Texas, most of which is in southern Comal County (fig. 1). The southwestern part of the area, about nine miles northeast of the San Antonio city limits, and a small part of the northwestern corner are in Bexar County. The city of New Braunfels is eight miles east of the quadrangle. Latitudes 29°45' and 29°37'30" form the northern and southern boundaries, respectively.

<u>Accessibility</u>.--Bat Cave quadrangle is easily accessible from most directions. Six paved roads provide excellent access to parts of the area, and numerous unpaved ranch roads can be used to reach more remote places, if a person has a jeep, truck, or carryall available.

From Interstate Highway 35 one can achieve access to the southern half of the quadrangle by traveling northwest and then southwest on FM 1337 to its intersection with Bat Cave Road. From New Braunfels the best route is Texas 46 west to FM 1863, which passes through the northern one-third of the map area. Schoental Road and Caverns Road link Bat Cave Road to FM 1863.

<u>Methods of Investigation</u>.--Geology of Bat Cave quadrangle was mapped during the spring of 1970. Wherever possible, aerial photograph stereo pairs with a scale of

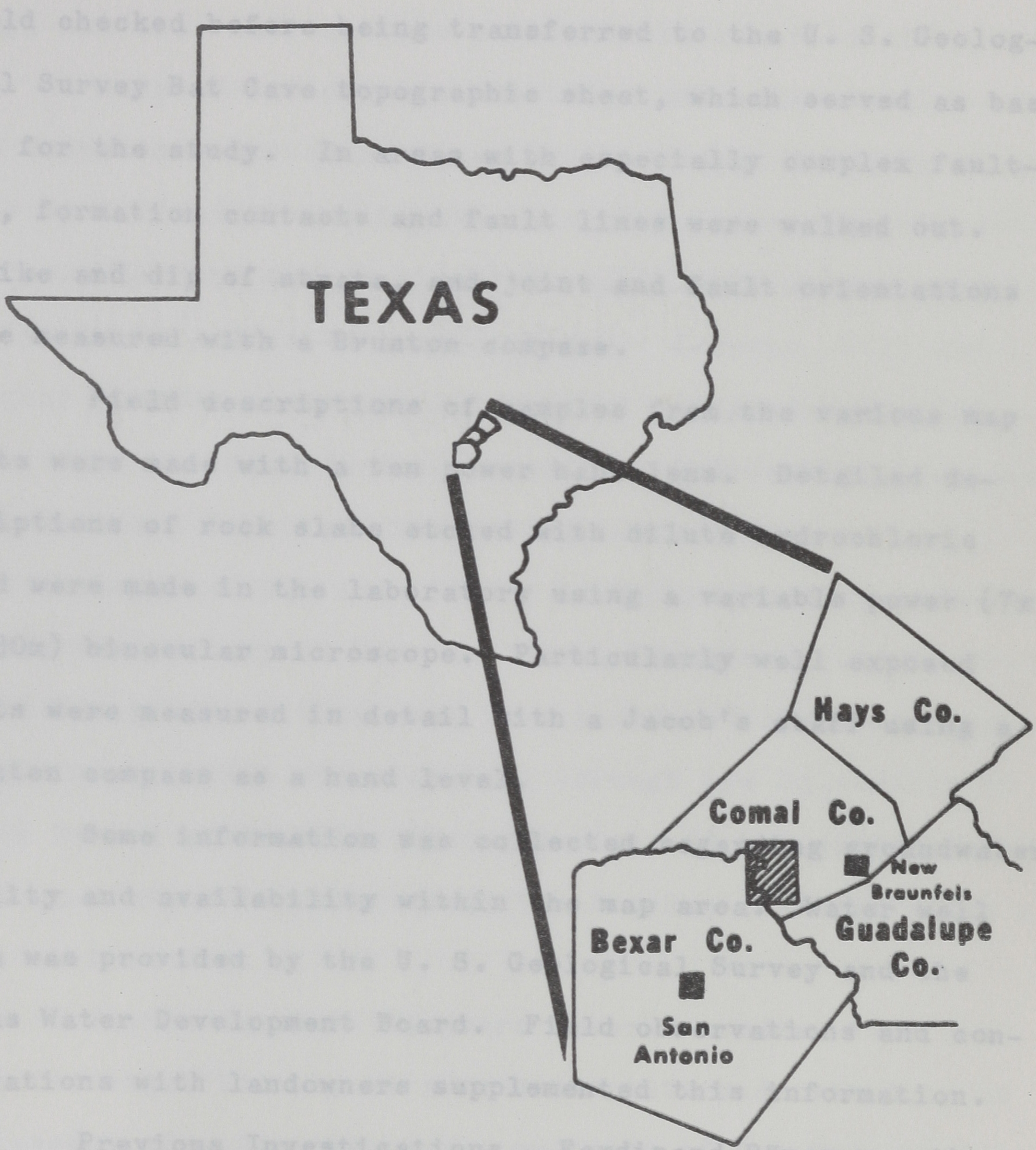

Figure 1.

Location of Bat Cave Quadrangle

1:24,000 were used to locate faults and formation contacts. Air photo interpretations of the geology were extensively field checked before being transferred to the U. S. Geological Survey Bat Cave topographic sheet, which served as base map for the study. In areas with especially complex faulting, formation contacts and fault lines were walked out. Strike and dip of strata, and joint and fault orientations were measured with a Brunton compass.

Field descriptions of samples from the various map units were made with a ten power hand lens. Detailed descriptions of rock slabs etched with dilute hydrochloric acid were made in the laboratory using a variable power (7x to 30x) binocular microscope. Particularly well exposed units were measured in detail with a Jacob's staff using a Brunton compass as a hand level.

Some information was collected regarding groundwater quality and availability within the map area. Water well data was provided by the U. S. Geological Survey and the Texas Water Development Board. Field observations and conversations with landowners supplemented this information.

Previous Investigations.--Ferdinand Römer was the first to study the geology, geography, and paleontology of south-central Texas. He came to the New Braunfels area to inspect the progress of German settlements. During several trips up the Guadalupe River and northeast toward Austin, he collected and described fossils from outcropping Cretaceous strata. Beginning in 1846, after Römer had returned to Germany, his observations were published in a series of reports.

Much of our present knowledge and understanding of the Cretaceous System in Texas can be traced directly to work done by R. T. Hill during the late 19th and early 20th centuries. Most of his publications dealt with strata cropping out in north and north-central Texas. However, Hill and Vaughan (1898b) described the geology and groundwater resources of the Edwards Plateau and Rio Grande Plain, an area that includes Comal and Bexar Counties.

Between 1925 and 1935 F. L. Whitney and his students mapped the geology of Hays and Comal Counties. Later, Dr. Keith Young edited this work in a series of 15 minute quadrangle maps, which are available through the University of Texas Bureau of Economic Geology. Some of the geology of Bat Cave quadrangle is recorded on the Bracken quadrangle map of this series.

Within the past 15 years several studies have contributed significantly to a more complete understanding of Cretaceous stratigraphy in the vicinity of Bat Cave quadrangle. Lozo and Stricklin (1956) described basal Cretaceous outcrops of central Texas and proposed a three-fold subdivision of the Trinity. Subsurface studies by Winter (1962) in south Texas and Tucker (1962b) in central Texas helped clarify regional stratigraphic relationships within the Comanche Series. In central Texas, as far south as Comal County, Martin (1961, 1967) and Moore (1961, 1964) examined and described exposures of the Washita and Fredricksburg Groups, respectively. Rose (1968) made a detailed lithostratigraphic study of the Edwards Formation in the central Texas subsurface and in the Edwards Plateau, west of the Balcones fault zone.

George (1952) and Arnow (1962) described the geology and groundwater resources of Comal and Bexar Counties, respectively. Their reports included small scale generalized geologic maps and cross sections.

Sayre and Bennett (1942), Pettit and George (1956), and Garza (1962, 1966) investigated the hydrology of the Edwards aquifer in the vicinity of San Antonio. Their efforts were directed toward determining storage capacity and amounts of recharge and discharge.

During a regional study of the Edwards underground reservoir between Austin and Del Rio, the U. S. Army Corps of Engineers (1964) examined a small area which had been considered as a possible dam site along Cibolo Creek near Bracken Bat Cave. Several shallow cores were taken and a geologic map was made of the potential dam site.

During a survey of Lower Cretaceous limestone and dolomite resources of Texas, Rodda _et al_. (1966) measured a section in, and collected and analyzed samples from, the Servtex Materials Company quarry in the southeastern corner of the quadrangle.

Reddell (1964) compiled and published locations, descriptions, and maps of Comal County caves. Beck (1968) speculated on the origin of some of these caves. Natural Bridge Caverns and Bracken Bat Cave, two large caves studied by these workers, lie within the quadrangle.

A number of University of Texas graduate students working under the supervision of Dr. K. P. Young added to the knowledge of the geology of Hays and Comal Counties by mapping and describing quadrangles (Abbott, 1966; Bills, 1957; Cooper, 1964; Davis, 1962; DeCook, 1956; Grimshaw, 1970; King, 1957; Noyes, 1957). The Mission Valley quadrangle, studied by King, adjoins the Bat Cave quadrangle along the northern half of its western boundary.

Acknowledgments.--I want to thank graduate students G. L. Dawe, P. L. Abbott, T. W. Grimshaw, R. E. Moran, and G. A. Bishop for their advice, assistance, and stimulating discussions of various aspects of central Texas geology. L. L. Davis and T. P. Clark deserve thanks for critically reading and editing the manuscript.

Daniel Evans of the Texas Water Development Board and Richard D. Reeves of the U. S. Geological Survey in San Antonio were of great assistance when I attempted to obtain information about groundwater resources in the thesis area.

Many thanks go to the residents of Bat Cave quadrangle. Without their cooperation this thesis project could not have been done. Special thanks are extended to Herman Blank, Arnold Reeh, Charles Lewis, Mr. and Mrs. Harry Heidemann, owners of Natural Bridge Caverns, and Shelly Burt, Manager of Servtex Materials Company quarry, for showing interest in the project and for allowing me unlimited access to their property.

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To Dr. Keith P. Young I extend my sincerest gratitude for suggesting the problem, supervising the research, providing guidance that helped me gain an insight into many of the geologic problems encountered during the course of the investigation, and editing the manuscript.

Finally, my wife, Jackie, deserves special note for her moral support and assistance in the preparation of parts of the manuscript.

PHYSIOGRAPHY

Climate.--Bexar and Comal Counties have a subhumid temperate climate with mild winters and hot summers. San Antonio and New Braunfels have mean January temperatures of 50.6°F. and 51.5°F., respectively, and mean July temperatures of 87.2°F. and 83.7°F. (Pettit and George, 1956, p. 6). Daily temperature fluctuations of 40° to 50° farenheit are not uncommon during the winter months. Daily maximums during the summer are almost always over 90°F. Annual precipitation averages 27 to 30 inches, principally from localized thundershowers. There is no distinct dry season. With a growing season of 270 to 280 days, the area is well suited climatically for a variety of crops.

Vegetation.--According to the Oxford Regional Economic Atlas of the United States and Canada (1967, p. 60) south-central Texas is covered by Savanna type vegetation with abundant mesquite, oak scrub, and juniper. Cuyler (1931) has demonstrated that certain trees and shrubs in this region are more abundant on the outcrops of different Cretaceous formations.

In Bat Cave quadrangle a good relationship between rock lithology and vegetation aids mapping. Live Oak (*Quercus virginiana*) is most abundant on outcrops of the Edwards Group, Buda Limestone, and Austin Chalk. Juniper

(*Juniperus virginiana*) flourishes on the Glen Rose Formation, Walnut Formation, Edwards Group and Buda Limestone. Sycamores (*Platanus occidentalis*) populate the alluvial deposits along Cibolo Creek in the northwestern part of the map area. Mesquite (*Prosopis juliflora*) prospers on Del Rio Clay, Eagle Ford Shale, Taylor Clay, and on residual, terra rosa soils of the Edwards Group. Prickly Pear (*Opuntia lindheimeri*) and Texas Persimmon (*Diospyros texana*) thrive on soils of the Edwards Group, but are also common on the Buda and Austin Limestones.

Topography.--Approximately 95 percent of Bat Cave quadrangle, dominated by rolling hills of low to moderate relief, lies within the Edwards Plateau. A prominent fault-line scarp along the trace of Comal Springs fault forms the boundary between the maturely dissected eastern margin of this physiographic province and the black prairies of the Gulf Coastal Plain province.

Elevation of the land surface ranges from approximately 720 feet in the southeastern part of the quadrangle to 1,250 feet near the northwestern corner. The total relief is 530 feet. Maximum local relief occurs along the western edge of the map area, where Cibolo Creek has incised resistant limestone and dolomite and formed a canyon with nearly vertical walls as much as 150 feet high.

GEOMORPHOLOGY

Drainage

Two intermittent streams, Cibolo Creek and Dry Comal Creek, drain Bat Cave quadrangle. Together with their tributaries, they form a dendritic pattern. Both streams are actively degrading their channels, and are in a youthful stage of the erosion cycle as is evidenced by their V-shaped cross valley profiles. Locally, faults and joints have strongly influenced orientation of stream segments. Structural control of the drainage is manifested at angular bends or irregular meanders, or at particularly straight channel segments aligned along, or parallel to faults.

Cibolo Creek drains the western one-third of the map area. This stream flows south with an average gradient of about 20 feet per mile. Its tributaries are relatively straight with gradients of 75 to 125 feet per mile. Two lines of evidence indicate that Cibolo Creek has undergone dynamic rejuvenation as a result of uplift of the Edwards Plateau and subsidence of the Gulf Coastal Plain (Thornbury, 1954, p. 142-147): (1) the incised meander in the northwestern part of the quadrangle, and (2) the lack of conformity between the broad open valley along the upper reaches of the stream and the canyon formed downstream between FM 1863 and Bracken. The steep gradient and narrow valley of the lower reaches may also be a function of the presence of more resistant strata of the Edwards Group.

Dry Comal Creek and its tributaries flow south and southeast, draining the eastern two-thirds of the quadrangle. Channel gradients are between 40 and 50 feet per mile. Locally, ingrown meanders with nearly vertical cutbanks as much as 80 feet high have formed along the creek.

South of Comal Springs fault the gradient of Dry Comal Creek decreases as the main channel turns northeast. At New Braunfels it joins Comal River, which eventually discharges into Guadalupe River.

Surficial Karst Features

Terra Rosa Soil.--A residual red soil, containing numerous chert nodules, mantles the surface of broad, flat uplands underlain by limestones of the Edwards Group. This soil was formed by weathering during the Pleistocene.

Karren and Lapies.--Etched, pitted, and grooved surfaces are commonly developed on limestone outcrops that have been subjected to surficial solution processes.

Sinkholes.--Numerous solution-formed depressions (dolines) and collapse sinks are present in areas underlain by limestone and dolomite of the Edwards Group. Locations of the larger ones are shown on plate 1. Most sinkholes in the quadrangle are shallow, only a few being as deep as 30 feet. Where residual red clay has formed a relatively impervious lining, water will be ponded for several weeks after a heavy rainfall. These depressions commonly are associated with aerial photo lineations that appear to be the surface traces of faults.

Caves

Extensive subsurface solution along joints and bedding planes has produced a number of caves including Comal County's two largest, Natural Bridge Caverns and Bracken Bat Cave. Locations of these two are noted on plate 1. The following discussion of the two major caves is based on work by Reddell _et al_. (1964) and Beck (1968), and on observations by the writer.

Natural Bridge Caverns.--The entrance to the caverns is in the bottom of a northwesterly elongated collapse sink, approximately 200 feet long, 40 feet wide, and 30 feet deep. From the entrance sink to the end of the northernmost room the cave trends approximately N. 10° W. for a straight line distance of 3,125 feet. The boundary between the Walnut Formation and the overlying Kainer Formation is near the elevation of the cave entrance. A narrow, tortuous crawlway originally extended 90 feet downward through limestone of the Walnut Formation to large galleries in dolomite and dolomitic limestone of the upper 150 feet of the Glen Rose

Formation. Construction of a larger entrance and elimination of the difficult descent accompanied commercialization in 1964.

Two joint sets oriented approximately N. 30° W. and N. 30° E. apparently controlled development of the cave passages. Beck (1968, p. 23-30) suggested that these caves may have been formed by rapidly flowing groundwater at or slightly beneath the water table. In support of this hypothesis he stated that contours on the potentiometric surface (Rhoades and Guyton, 1955, fig. 5) indicate convergence of groundwater flow lines through this area. Although Beck's conclusions may be correct, his evidence is weak. The present water table is at least 50 feet below the lowest point in the caverns. In the past, when the water table was high enough to fill the cave passages, the configuration of the surface may have been significantly different.

Shapes of galleries within Natural Bridge Caverns suggest that solution processes operating in the phreatic zone played a major part in their formation. Subsequent downcutting by Cibolo Creek drained the cave passages, allowing dripstone deposition to begin.

Why have Natural Bridge Caverns formed in dolomite of the Glen Rose Formation, when only small caves are known to be present within more soluble limestone of the Edwards Group? Outcrop weathering and rapid leaching of calcite matrix causes the dolomite to be moderately friable and less resistant to erosion than the relatively pure limestone of the Edwards Group. Perhaps, when the Glen Rose was in the phreatic zone, a similar mechanism operated along joints. Initial enlargement of joints was probably by solution of both calcite and dolomite. Following this stage, the corrasive action of relatively rapid groundwater flow may have removed the dolomite as the calcite matrix was selectively dissolved.

Travertine is presently being precipitated inside the caverns by evaporation of vadose seepage. Numerous colorful stalactites, stalagmites, columns, and drapes are forming throughout the passages and galleries.

<u>Bracken Bat Cave</u>.--The entrance to Bracken Bat Cave is at the bottom of a collapse sinkhole, 100 feet in diameter, developed in the Kainer Formation (frontispiece). The ceiling and floor of the main passage are at depths of 66 feet and 96 feet, respectively. The cave trends N. 23° W. for 430 feet. Comparison of data from Reddell (1964, p. 10) with geologic (plate 1) and topographic maps of the area leads to the conclusion that the main passage is approximately at the contact between the Glen Rose and Walnut Formations, and is developed along a joint set perpendicular to Bat Cave fault.

Bat Cave fault, 300 yards to the south of the entrance sink, undoubtedly influenced the location and development of Bracken Bat Cave and nearby Natural Bridge Caverns. Tensional stresses causing this faulting probably produced a large number of intersecting joint sets, making conditions favorable for solution of the bedrock, *i.e.*, increasing the available surface area, while at the same time permitting the maximum amount of phreatic water to flow through the area. It is possible, if not probable, that other such caves may exist north of Bat Cave fault, along strike, but are undiscovered because they have no surface expression.

One of the world's largest colonies of the Mexican Free-Tailed Bat (*Tadarida brasiliensis mexicana*) resides in this cave during the spring, summer, and fall (Reddell, 1964, p. 10). Large accumulations of bat guano, resulting from their habitation, have been commercially exploited.

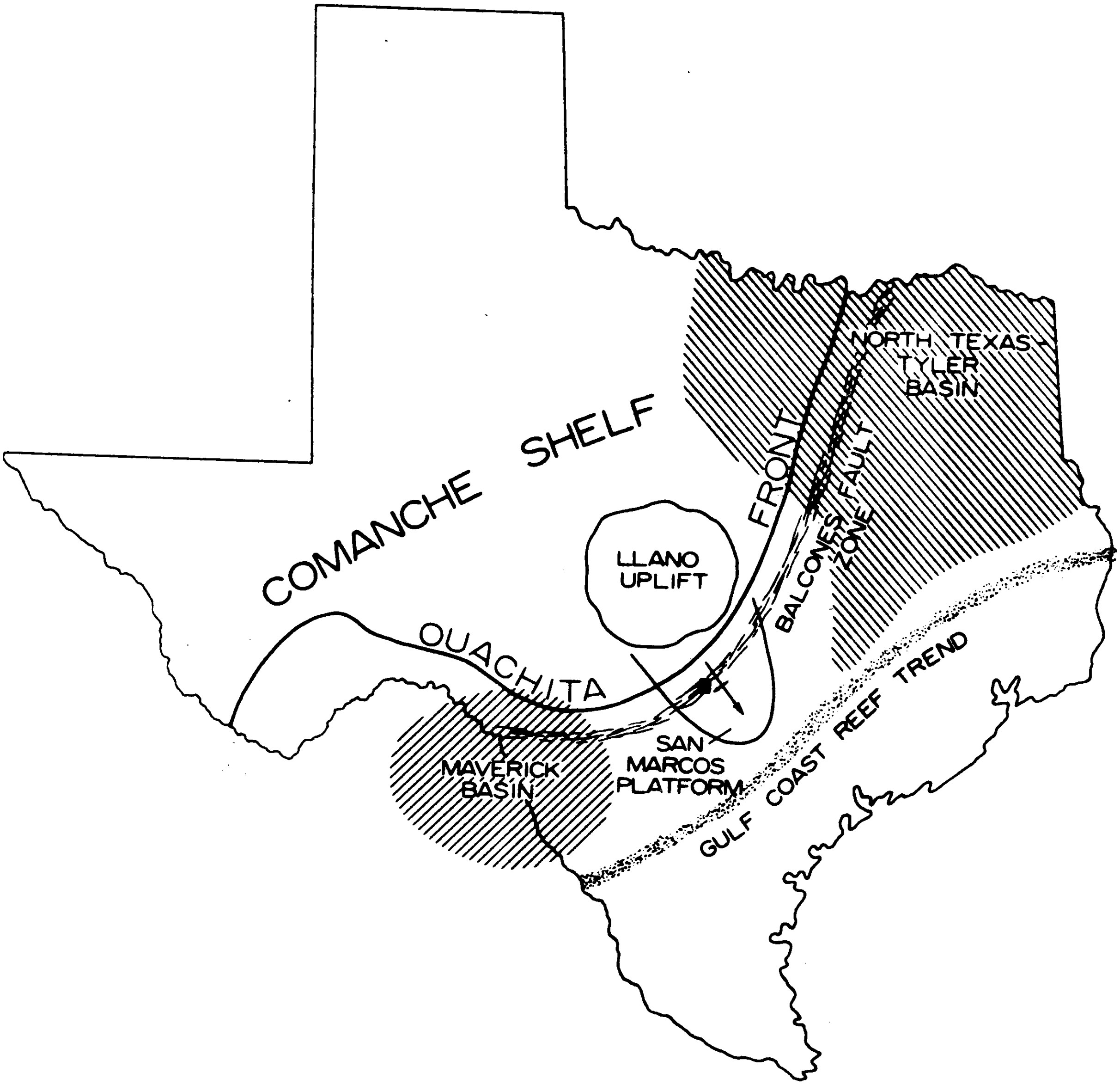
REGIONAL GEOLOGIC ELEMENTS

Texas Craton and Ouachita Structural Belt.--The Texas craton is a northwesterly elongated, stable Precambrian basement element consisting mostly of granitic rocks. It is the most fundamental basement element in Texas, extending from the central part of the state into southeastern New Mexico. The Llano uplift is a surface expression of a portion of the craton (fig. 2). The age of rocks in the Llano area has been determined, radiometrically, to be approximately one billion years (Flawn, 1956, p. 7, 8).

The Ouachita structural belt, a complex of folded and thrust-faulted Paleozoic metasedimentary rocks, forms the southern and southeastern margins of the Texas craton (Flawn, 1956, p. 7). Orogenic forces, active during the late Paleozoic, compressed sedimentary rocks of the Ouachita geosyncline northward against the stable Texas craton. The deformed belt extends more than 1,300 miles in a sinuous trend from a point in east-central Mississippi, west and southwest through Texas into Mexico. Two tectonic provinces have been recognized within the Ouachita system (Flawn et al., 1961, p. 3):

> . . . a frontal zone bordering the craton where deformation was by flexure, analagous to the Valley and Ridge tectonic province of the Appalachian system, and an interior zone where deformation was mainly by shear, analagous to the Blue Ridge tectonic province of the Appalachian system.

The boundary between the Ouachita foldbelt and the



Regional Geologic Elements

Figure 2.

Texas craton is a zone of crustal weakness which influenced depositional facies of Cretaceous rocks, and along which faults of the Balcones system developed (Muehlberger and Kurie, 1956, p. 43).

Bat Cave quadrangle is located over the frontal zone of the Ouachita structural belt. Flawn *et al*. (1961, pl. 2) have inferred that basement rocks of the Mississippian and Pennsylvanian systems are present beneath the area.

Balcones Fault System.--A band of high-angle, *en echelon*, normal faults with dominantly down-to-the-coast displacement extends from Val Verde County, east, northeast, and north to McLennan County, or possibly to Ellis County (Reaser, 1961, p. 1759). This zone of fractures is parallel to the subcrop of the Ouachita front as it wraps around the Llano uplift. Between Austin and San Antonio the surface expression of the system is a prominent fault-line scarp, the Balcones Escarpment.

Crustal extension, caused by uplift of the Edwards Plateau and accompanying subsidence of the Gulf of Mexico basin, produced a broad, northeast trending graben, bounded on the east by up-to-the-coast faults of the Mexia-Luling system (Weeks, 1945, p. 1734; Muehlberger and Kurie, 1956, p. 43). The presence of numerous limestone fragments and Cretaceous fossils in the Miocene Oakville Formation indicates that considerable movement along the Balcones system must have occurred at that time (Weeks, 1945, p. 1736).

A total of 1,500 feet of throw was recorded by George (1952, p. 1) for the Balcones fault zone in Comal County. Cross sections through Bexar County by Arnow (1963) indicate a total displacement of approximately 2,000 feet. Within Bat Cave quadrangle the strata have been displaced, downward, a total of 1,200 feet to the southeast.

Comanche Shelf and Gulf Coast Reef Trend.--Lower Cretaceous rocks of central Texas were deposited on a broad, flat, generally submerged plane, termed the Comanche shelf by Rose (1968, p. 1). This area of dominantly shallow water, platform, and lagoonal deposition was separated from deeper water of the ancestral Gulf of Mexico basin by the Gulf Coast reef trend (Hendricks and Wilson, 1967, p. 3). This group of vertically stacked barrier reefs, of which the upper part was termed the Stuart City reef by Winter (1962, p. 85), developed several miles inland from, and approximately parallel to, the present Texas coastline. Rudist, coral, and algal material formed the framework of individual reefs. Each episode of organic buildup along the shelf edge was followed by a period of rapid terrigenous clastic influx (Hendricks and Wilson, 1967, p. 6).

San Marcos Platform.--The broad, relatively flat, positive feature extending southeast from the Texas craton and separating the Maverick basin (Winter, 1962, p. 85) on the southwest from the North Texas - Tyler basin (Fisher and Rodda, 1967, p. 54) was named the San Marcos arch by W. S. Adkins (1933, p. 266). This positive element has no topographic expression, but must be inferred from thinning of the Georgetown Limestone, Del Rio Clay, Eagle Ford Shale, and Austin Limestone over its crest. Winter (1962, p. 84) preferred to call it the San Marcos platform, because it is not a structural arch, but is an area that subsided more slowly than basins on either side. Adkins (1933, p. 266) thought that San Marcos River flowed along the axis of the platform. However, data collected from surface mapping by Bills (1957), King (1957), Noyes (1957), Townsend (in progress), and the author suggest that the axis probably trends through the vicinity of New Braunfels.

STRATIGRAPHY

Rocks of the Cretaceous System, ranging in age from Albian to Senonian, crop out in Bat Cave quadrangle (fig. 3). All or part of ten formations, consisting predominantly of carbonate rock, and having a total thickness of approximately 1,050 feet, are exposed within the map area. The upper 240 feet of the Glen Rose Formation crops out in the northwestern corner. Progressively younger rocks are present to the southeast because of down-to-the-coast normal faulting. The Taylor Clay is the youngest Cretaceous formation within the thesis area.

Alluvial and colluvial deposits of the Quaternary System, locally up to 30 feet thick, cover older Cretaceous strata along the bottoms of stream valleys.

Cretaceous System

R. T. Hill (1887) first correctly interpreted the sequence of Cretaceous strata in Texas, proposing that the system be subdivided into two provincial series, Comanche and Gulf. He believed that these series were great sedimentary cycles. Hill stated,

> . . . each series represents a more or less complete ternary succession of strata, *i.e.* the succession of deposits first along shore, followed by deepening, then by shallowing deposits to land again, as laid down by each subsidence and elevation of the ocean bottom.

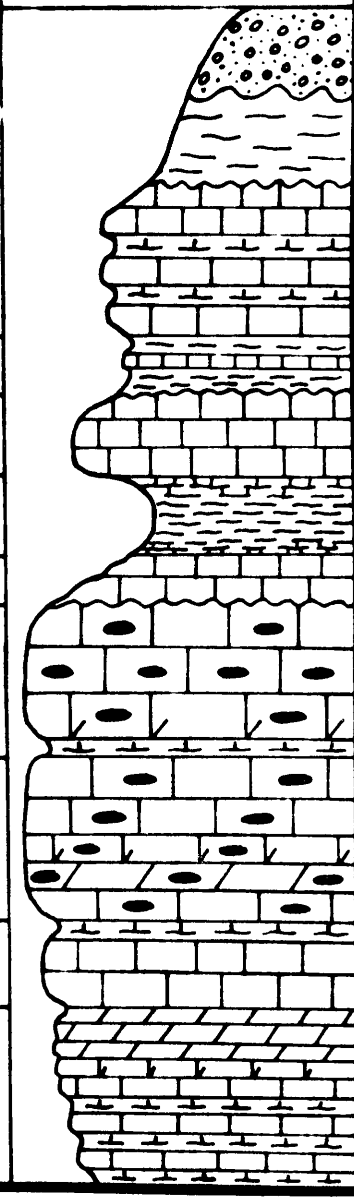
System	Local Series	Series	Stage	Group	Formation	Exposed thickness in feet	Lithology
QUATERNARY					Alluvium	0-30	
CRETACEOUS	Gulf	Upper Cretaceous	Senonian		Taylor	50?	
CRETACEOUS	Gulf	Upper Cretaceous	Senonian		Austin	150?	
CRETACEOUS	Gulf	Upper Cretaceous	Turonian		Eagle Ford	20	
CRETACEOUS	Comanche	Upper Cretaceous	Cenomanian		Buda	65	
CRETACEOUS	Comanche	Upper Cretaceous	Cenomanian		Del Rio	35-50	
CRETACEOUS	Comanche	Upper Cretaceous	Cenomanian		Georgetown	15	
CRETACEOUS	Comanche	Lower Cretaceous	Albian	Edwards	Person	170	
CRETACEOUS	Comanche	Lower Cretaceous	Albian	Edwards	Kainer	240?	
CRETACEOUS	Comanche	Lower Cretaceous	Albian		Walnut	48	
CRETACEOUS	Comanche	Lower Cretaceous	Albian		Glen Rose	240	

Figure 3. Generalized Stratigraphic Section

Imlay (1944, p. 1005-1007) modified Hill's subdivision by lumping basal Cretaceous units into the Coahuila Series, and restricting the base of the Comanche Series to the base of the *Dufrenoyia justinae* zone (base of upper Aptian). Texas stratigraphers generally have not adopted Imlay's revisions (Lozo and Stricklin, 1956; Young, 1967, p. 10). Therefore, Hill's terminology will be used in this thesis.

Comanche Series

Hill (1887) named the Comanche Series after the north Texas town of Comanche. He intended it to include all the rocks from the base of the Cretaceous to the top of the Buda Limestone (Hill, 1901).

Three sedimentary subcycles of the major cycle, the series, were recognized by Hill (1894, p. 333-335) and termed, in ascending order, the Trinity, Fredricksburg, and Washita Divisions. Adkins (1933) considered these units to be groups, abandoning the term division. However, Young (1967, p. 11) pointed out that since Hill's physically defined division has time-stratigraphic implications, rock-stratigraphic terms such as group are not applicable. Although many Texas stratigraphers use the division in regional work, it is not formally recognized by the American Commission on Stratigraphic Nomenclature (1961).

Further consideration of the confusing problems relating to the nomenclature and boundaries of the Trinity, Fredricksburg, and Washita is beyond the scope of this investigation. Anyone having an interest in this aspect of Cretaceous stratigraphy should refer to Young (1967). The text of the following pages will be restricted to descriptions of mappable rock units.

Pre-Glen Rose Formations.--Since very little subsurface data is available for the map area, only broad inferences can be made concerning strata below the Glen Rose Formation. The following brief discussion is based principally on work by Lozo and Stricklin (1956), Cooper (1964), and Young (1967).

The Sycamore Conglomerate, the basal Cretaceous unit, rests unconformably on Mississippian and Pennsylvanian sedimentary and metamorphic rocks of the Ouachita facies. The conglomerate may locally reach a thickness of 900 feet. The Hosston Sandstone and Sligo Limestone are downdip subsurface equivalents of the Sycamore, which does not crop out in Comal or Bexar County. The Hosston and Sligo are a total of 610 feet thick at the Pan American No. 1 Schmidt well in northwest Guadalupe County.

Hammet Shale, Cow Creek Limestone, and Hensel Sandstone consecutively overlie the Sycamore at the outcrop. In the subsurface these units are included in the Pearsall Formation (Imlay, 1945, p. 1441), which is 175 feet thick at the

Pan American No. 1 Schmidt well (Tucker, 1962a, p. 100). In western Comal County the Cow Creek consists of sandy, fossiliferous, intraclastic calcarenite, whereas sandy, dolomitic micrites comprise the Hensel. Downdip the Bexar Shale occurs immediately beneath the Glen Rose Formation (Tucker, 1962b, p. 192).

Glen Rose Formation.--Shumard (1860) applied the term "*Caprotina* Limestone" to exposures of marl and limestone in Travis County, Texas. Later, Hill (1891, p. 504-507) formally renamed this sequence of "alternating beds" the Glen Rose Limestone and established the type section near the town of Glen Rose, Somervell County.

The Glen Rose Formation transitionally overlies the Hensel at the outcrop. A thin, regionally persistent biosparite bed, which contains small steinkerns of the clam *Corbula harveyi* (Hill), permits the formation to split into two members. Isopachous maps made by Tucker (1962b, p. 188, 189) show thicknesses of 400 to 500 feet for the Lower Member and 350 to 400 feet for the Upper Member within the map area. The Glen Rose probably is between 800 and 900 feet thick.

The Lower Glen Rose is composed of the following lithologies, in ascending order: 1) dolomitic micrite and biomicrite, 2) rudistid biolithite as tabular coral and rudistid reefs, and 3) marly biomicrite interbedded with thin biosparites, both containing abundant *Orbitolina texana*

Römer. The Upper Glen Rose contains two evaporite-dolomite horizons, one just above the "Corbula" bed and another 200 feet higher. Both are probably in the subsurface in Bat Cave quadrangle. A section of interbedded marly biomicrite and resistant biosparite separates these two distinctive horizons.

The top 120 to 125 feet of Glen Rose Formation, which crops out within the map area, consists of finely crystalline dolomite and dolomitic biomicrite interbedded with a few, two foot thick, fossiliferous intrasparites. The amount of limestone decreases upward, with the top 75 feet being almost entirely dolomite. Light tan dolomite units change to dark gray or black upon weathering, becoming moderately friable and recessive with respect to limestone above and below. The best exposures of Upper Glen Rose dolomitic beds are in cliffs along Cibolo Creek, southeast of Hidden Valley fault (fig. 10).

A sequence of two to three foot thick, resistant biosparites and poorly indurated, nodular, argillaceous biomicrite beds occurs below the upper dolomitic interval. These alternating resistant and non-resistant beds crop out northwest of Hidden Valley fault, where weathering and erosion have produced circular hills with terraced slopes.

Because only the uppermost 240 feet of the Glen Rose Formation is exposed within a small part of the thesis area, subdividing was not attempted. Abbott (1966), Cooper (1964), and Grimshaw (1970) examined nearly complete sections of this formation in western Comal and Hays Counties. Grimshaw's Member G probably is correlative with the upper dolomitic interval of the Bat Cave area. The contact between the upper dolomites and underlying beds of limestone forms a prominent topographic bench, which can be traced on air photos over large areas (G. L. Dawe, 1971, oral communication).

Moore (1964, p. 6) stated that the Glen Rose is conformable with the overlying Walnut Formation in Comal County. Within the map area the contact between the two is poorly exposed, and it could not be accurately described. Below resistant limestone of the Walnut is an eleven foot interval that contains chunks of banded travertine and recrystallized limestone which are assigned to the Glen Rose.

Gastropod and clam steinkerns, and ostracods commonly occur in limestone and marl beds of the Glen Rose Formation. Oyster shell fragments and miliolids are particularly abundant in biosparites and intrasparites. The gastropods, _Tylostoma_ sp. and _Nerinea_ sp., and the algal fruiting body, _Porocystis globularis_ Giebel, were recognized in the Glen Rose.

Walnut Formation.--Hill (1891, p. 512) proposed the name "Walnut Formation" for strata cropping out near the town of Walnut (now Walnut Springs) in Bosque County. Limestone strata totaling 48 feet in thickness within Bat Cave quadrangle have been assigned this name.

Well indurated, pelletal biomicrite and fossiliferous pelsparite, in beds four inches to two feet thick, comprise the lower 43 feet of this formation. On a fresh surface beds appear yellowish brown to grayish orange, but are medium to dark gray and nodular when weathered. Gastropods, oyster shell-fragments, and ostracods are common throughout the interval. Numerous cavities, up to six inches in diameter and lined with very coarsely crystalline calcite, occur near the base of the unit. Best exposures of this resistant limestone interval are along the canyon of Cibolo Creek in the northwestern part of the quadrangle.

The upper five feet of the Walnut consists of clayey, sandy, slightly glauconitic biomicrite beds, less than an inch thick and containing whole valves of the oyster _Exogyra texana_ Römer. A few echinoid spines and gastropod and clam steinkerns occur in this unit. Scattered, poorly sorted, rounded, frosted, medium to coarse, quartz sand grains comprise 10 to 15 percent of most rock samples. This bed may be the southern continuation of Moore's Bee Cave Member (1961, 1964, p. 11). An excellent outcrop is along a dirt road on the Heidemann Ranch north of Caverns Road, about 2.5 miles southwest of its intersection with FM 1863.

The contact of the Walnut Formation with the overlying

Edwards Group is conformable. The boundary between the two can be readily distinguished in the field because of the unique lithology and recessive character of the uppermost bed in the Walnut (fig. 4). However, because this "Bee Cave" interval is thin, tracing the contact on air photos may be difficult, especially where slopes are steep.

The following fossils were identified in the Walnut Formation:

Pelecypoda:
- *Exogyra texana* Römer
- *Trigonia* sp.
- *Texigryphaea* sp.

Gastropoda:
- *Nerinea* sp.

Edwards Group.--The rock unit now called Edwards was first termed "Caprina Limestone" by Shumard (1860, p. 584). Hill (1889, p. 5) referred to it as the "Barton Creek Limestone." Finally, Hill and Vaughan (1898a) proposed the name "Edwards Formation" for the rudistid-bearing, cherty limestone. Adkins (1933, p. 339) designated Barton Creek near Austin as the type locality.

Nomenclature for the Edwards has remained relatively unchanged until the last few years. Rose (1968) thoroughly investigated the lithostratigraphy of this rock unit in the Edwards Plateau and in the central Texas subsurface. Rose (in press) suggests elevating the traditional "Edwards" to group status and formally designating two new formations.

Rose's subsurface subdivision of the Edwards can be applied to strata cropping out in Bat Cave quadrangle. Therefore, his terminology will be used in this thesis with only slight modification.

Kainer Formation.--Rose (1968, p. 33) has proposed the name "Kainer" for the lower unit of the Edwards in the subsurface of central Texas. He has designated a portion of the core from the Shell No. 2 Charles Kainer, Person Field, Karnes County, Texas, as the type section.

In Bat Cave quadrangle the Kainer consists mostly of light yellowish gray, locally honeycombed and cherty, rudistid and caprinid-bearing limestone in beds six inches to five feet thick. Well indurated oösparite and intrasparite, containing miliolids, oyster shell-fragments, and small gastropod steinkerns, comprise the upper 56 feet. These beds commonly exhibit horizontal current lamination or low angle cross-stratification. Below this interval is a sequence of porous, coarsely crystalline limestone interbedded with more resistant miliolid biosparite, intrasparite, and mollusc shell-fragment biomicrite. Pockets of red clay and pulverulent limestone occur locally in porous recrystallized beds. A few thin dolomitic layers are in the lower half of the formation.

Outside the map area the middle and lower parts of the Kainer are known to be highly dolomitic. However, very little dolomite seems to occur where these intervals crop out in the quadrangle. Conditions may not have been favorable for dolomite formation here. Alternatively, perhaps the dolomite did exist, but vadose water diagenetically altered or replaced it with coarsely crystalline calcite (dedolomitization). In view of the large amount of coarsely crystalline limestone in the Kainer, the second explanation may have considerable merit.

Dark brown to black chert occurs as lenticular nodules in zones parallel to bedding planes, and as irregular nodules scattered through a few limestone beds. Pittman (1959, p. 131-134) attributed the origin of the chert to metasomatic replacement of limestone and dolomite by silica from sponge spicules, prior to sediment lithification. Residual chert regolith mantles flat uplands underlain by the Kainer Formation.

Since a complete section of the Kainer is not exposed in any single fault block within the quadrangle, it was impossible to determine precisely its total thickness. Rose (1968, p. 204-205), in his description of the Selma core from a location two miles southwest of Bat Cave quadrangle, lists a thickness of 280 feet for the interval from the top of the Glen Rose Formation to the base of the Person Formation. The Walnut Formation was not recognized in this core, possibly because of a downdip facies change. Therefore, the Kainer Formation is estimated to be 230 to 240 feet thick where the Walnut is present.

The Kainer is conformable with the underlying Walnut Formation and is conformably overlain by the Person Formation. The best and most complete exposures of the unit are in cliffs along Cibolo Creek between Bat Cave fault and Waco (Hueco) Springs fault.

The following fossils were recognized in the Kainer Formation:

Pelecypoda:
- _Chondrodonta_ sp.
- _Toucasia_ sp. — NOTE

Gastropoda:
- _Nerinea_ sp.

Person Formation.--The term "Person" is proposed by Rose (1968, p. 38) for the upper unit of the Edwards in the central Texas subsurface. The type section is in the core from the Standard of Texas No. 1 Wiatrek, Person Field, Karnes County. In Bat Cave quadrangle this interval includes 160 to 170 feet of strata. For mapping purposes it has been informally subdivided into a lower "Doctor Burt" Member and an unnamed Upper Member.

Doctor Burt Member.--Thin, flaggy beds, one to three inches thick, of dense, argillaceous micrite and biomicrite comprise the basal 22 feet of the Person Formation in the map area (fig. 5). The unit appears very pale orange on a fresh

Figure 4. Contact between Walnut and Kainer Formations. Eastward view along Caverns Road near where it intersects FM 1863. Staff in center of photo is five feet long.

Figure 5. Doctor Burt Member. Westward view showing characteristic nodular appearance. Photo was taken along a dirt road, 0.8 miles southeast of Bracken Bat Cave on Arnold Reeh Ranch. Staff in center of photo is five feet long.

surface but is light gray and nodular when weathered.

The base of the Doctor Burt is conformable with the top of the Kainer Formation. Generally, a prominent topographic bench forms at the contact between the two because clayey beds of the Doctor Burt weather and erode more rapidly than do underlying more resistant limestone beds of the Kainer. This break in slope is visible on air photos, thus permitting the boundary between the two units to be traced readily over large areas. Soils are thin and vegetation relatively sparse on outcrops of this member. Consequently, it appears much lighter on air photos than do units above and below.

The name "Doctor Burt" was first applied by Pavlovic to a regionally persistent marly ammonite-bearing zone in the Edwards Plateau (Young, 1966, p. 8). Although the interval mapped during this investigation is similar lithologically to Pavlovic's ammonite zone, the two are not entirely equivalent in time (Rose, 1970, p. 2790). The unit described in this thesis is equivalent to the upper part of the Burt Ranch Member in the Edwards Plateau (Rose, in press) and to the Regional Dense Bed in the subsurface, which has been linked to part of the Kiamichi Formation of north Texas (Tucker, 1962b, p. 206-209).

Exposures of the Doctor Burt are restricted to an area between Bat Cave fault and Waco (Hueco) Springs fault.

Best outcrops of the unit are on the Arnold Reeh Ranch along the dirt road leading to Bracken Bat Cave.

Caprinid, gastropod, and clam steinkerns are common in the lower five feet of the Doctor Burt. The following fossils were collected and identified:

Pelecypoda:
- *Exogyra texana* Römer
- *Pleuromya knowltoni* (Hill)
- *Protocardia* sp.
- *Trigonia* sp.
- *Caprinuloidea* sp.

Gastropoda:
- *Lunatia* sp.

Ammonoidea:
- *Adkinsites imlayi* Young

Upper Member.--Above the Doctor Burt Member the Person consists of 140 to 148 feet of yellowish gray, very resistant limestone in beds six inches to five feet thick. Most beds in the section are composed of pelletal mollusc shell-fragment biomicrite or rudistid and caprinid biomicrudite. Only a few one to two foot thick beds of biosparite, associated with zones of lenticular chert nodules, are in the Upper Member of the Person. Near the base, a few biomicrites are dolomitic.

Locally, recrystallized, honeycombed strata contain pockets of red clay, pulverulent limestone and dolomite. At the Servtex Materials Company quarry, where the Upper Member is best exposed, rodent incisors and salamander bones occur in red clay that fills solution cavities in the limestone (E. L. Lundelius, oral communication). The clay may represent a former terra rosa soil washed into caves during the Pleistocene.

A thin, dark red soil and residual chert regolith usually cover the upper part of the Person in areas of low relief. Mesquite trees, which thrive on this type of soil, grow abundantly on the flat uplands.

The contact of the Person Formation with the overlying Georgetown Limestone is generally believed to be disconformable (Moore, 1964, p. 26; Young, 1967, p. 26; Rose, 1968, p. 67). Within the map area good exposures of the contact are uncommon. However, on the Riedel Ranch, one-half mile east of the junction of Caverns Road and Bat Cave Road, a bulldozer has scraped off the Georgetown, revealing a bored surface at the top of the Person (fig. 6). In other parts of south-central Texas Martin (1961) recognized a bored corrosion zone at the top of the Person, but stated that it probably does not represent a significant period or amount of erosion.

Rose (1972) says 100 feet was removed,

Shells of fossil organisms in the Upper Person commonly have been replaced by silica. Several silicified colonial corals and pieces of wood were collected from float near the top of the formation. The following fossils were observed:

Pelecypoda:
Pecten sp.
Caprinuloidea sp.
Monopleura sp.
Toucasia sp.

Gastropoda:
Cerithium sp.
Nerinea sp.

Georgetown Limestone.--Hill (1901, p. 262) applied the name "Georgetown" to strata between the Edwards Limestone and Del Rio Clay, south of the Brazos River. A sequence of limestone and marl on the San Gabriel River at Georgetown, Williamson County, was established as the type section. Adkins (1924, p. 38) found that the Georgetown Formation could be differentiated into seven members. Wilbert (1967) and Martin (1961) studied the history and regional stratigraphic relationships of these members in central and south-central Texas, respectively.

Approximately 15 feet of grayish orange, six inch to two foot thick beds of dense limestone with a few, two to three inch interbeds of marl, containing whole valves of the oysters *Texigryphaea* sp. and *Exogyra* sp., comprise the Georgetown Formation. The limestone is dominantly packed oyster shell-fragment biomicrudite with scattered glauconite pellets making up three or four percent of some samples. Veinlets of sparry calcite occur throughout most limestone beds. Weathered outcrops of the Georgetown appear yellowish gray to medium gray and nodular. Fossil fragments are usually stained yellowish brown as a result of replacement of calcite by limonite or hematite.

Outcrops of the Georgetown are restricted to the area between Waco (Hueco) Springs fault and Comal Springs fault. There are good exposures on the Riedel Ranch, east of Caverns Road, and on the Blank Ranch about 1.5 miles northeast of the ranch house and 300 yards north of Eikel-Blank Dam, which is on Dry Comal Creek.

The contact between the Georgetown and the overlying Del Rio Clay is obscured by slumping and erosion of the poorly indurated clay. Martin (1961, p. 31) stated that in other parts of south-central Texas the boundary between the two formations is conformable and gradational.

The Georgetown contains the most diverse fossil assemblage of any of the formations studied. Gastropods, ostracods, foraminifers, serpulids, calcispheres, echinoid spines, oysters, and venerid clam steinkerns are common throughout the unit. The following fossils were identified:

Brachiopoda:
Kingena wacoensis Römer

Ammonoidea:
Plesioturrilites brazoensis Römer
Mortoniceras sp.

Foraminifera:
Globigerina sp.
Textularia sp.

Echinoidea:
Holectypus limitis Böse

Pelecypoda:
- *Texigryphaea washitaensis* (Hill)
- "*Gryphaea*" *gibberosa* Cragin
- *Arctostrea* sp. aff. *carinata* Lamarck
- *Pecten* sp.
- *Neithea* sp.
- *Trigonia* sp.
- *Pachymya austinensis* Shumard
- *Exogyra* sp.

Del Rio Clay.--Shumard (1860, p. 583, 586) called this unit the "*Exogyra arietina* Marl." Cragin (1894, p. 40-43) renamed it the "Grayson Marl" after outcrops near Denison, Grayson County, Texas. Hill and Vaughan (1898b) applied the name "Del Rio" to clays in the vicinity of Del Rio, Val Verde County, Texas. Hill (1901), apparently realizing that two different names had been assigned to essentially one continuous rock body, restricted the term "Del Rio" to strata between the Georgetown and Buda Limestones, south of the Brazos River. Adkins and Lozo (1951) emphasized that there is a lithologic difference between rock called "Grayson" and rock called "Del Rio."

In the thesis area the formation consists, principally, of olive gray, poorly indurated, plastic, calcareous clay in beds less than an inch thick. Locally, a few one-half to two inch thick beds of horizontally laminated calcareous siltstone occur in the unit. Resistant lenses of packed *Exogyra arietina* biomicrudite, up to three inches thick, are common. Weathered clay is typically dusky yellow, whereas the siltstones appear yellowish brown. Outcrops of the Del

Rio are generally covered with specimens of the distinctive oyster _E. arietina_ Römer and pebble-size ironstone nodules. The Del Rio thickens from about 35 feet near the intersection of Schoental Road and FM 1863 to about 50 feet on the Classen Ranch at the quadrangle's southwestern corner.

Aggregates of selenite crystals are common as thin horizontal lenses (fig. 7). The long axes of the crystals are oriented perpendicular to bedding. Sulfate necessary to produce the gypsum probably results from surface or near surface oxidation and hydration of pyrite or marcasite (Keller, 1966, p. 19). Later, evaporation of saturated vadose water causes precipitation of calcium sulfate along bedding planes and slip surfaces.

The Del Rio is easy to recognize both in the field and on air photos. It usually supports only sparse vegetation, consisting of a few grasses and mesquite. On low slopes subjected to prolonged weathering a thick dark brown soil forms, permitting cultivation. The extremely low permeability of the unit makes it ideal for the construction of water tanks.

Slumping of overlying blocks of Buda Limestone and erosion and outwashing of Del Rio Clay over the underlying Georgetown tends to obscure their respective depositional contacts. Martin (1961, p. 31, 46) reports that, regionally, the upper and lower boundaries of the formation are

Figure 6. Contact between Person Formation and nodular Georgetown Limestone. Top surface of Person has been bored by pholads. Southeastward view near dam on Riedel Ranch. Staff in center of photo is five feet long.

Figure 7. Lenses of gypsum (selenite) crystals in Del Rio Clay. Photo was taken on Herman Blank Ranch just north of Eikel-Blank dam. Blocks of limestone in background are from the Georgetown.

gradational, intercalating with the Buda and Georgetown Limestones, respectively.

Exogyra arietina Römer is by far the most abundant species in the Del Rio Clay. In addition to numerous foraminifers, the formation contains the following:

Gastropoda:
- *Turritella* sp.

Ammonoidea:
- *Turrilites bosquensis* Adkins

Pelecypoda:
- *Texigryphaea roemeri* (Marcou)
- *Exogyra drakei* Cragin
- *Pecten* (*Neithea*) *texanus* Römer
- *Pecten* sp.
- *Trigonia* sp.
- *Protocardia* sp.
- *Cyprimeria* sp.

Buda Limestone.--Hill (1890, p. xxiii) first formally defined this rock unit, calling it the "Shoal Creek Limestone," for exposures along Shoal Creek in Austin, Texas. Because this name had previously been applied to another formation, Vaughan (1900, p. 18), following Hill's suggestion, renamed it "Buda Limestone." General lithofacies of the Buda throughout central and west Texas were studied by Hixon (1959). Martin (1961, 1967), who made a detailed investigation of the petrography and regional stratigraphic relationship of outcrops in central Texas, recognized two lithically distinct members. Within Bat Cave quadrangle the Buda was not subdivided because of difficulty in locating the boundary between the two members on weathered slopes.

The Buda is composed of about 65 feet of pale orange to dark yellowish orange, dense, nonporous limestone in beds from one to four feet thick. The lower part of the formation consists of slightly glauconitic (two to three percent), burrowed, pelletal mollusc shell-fragment biomicrite. Intraclastic biomicrite and fossiliferous intramicrite comprise the upper part. Fossil shell material in these limestones commonly has been replaced by sparry calcite. Weathered samples typically appear light gray, but intraclastic rocks may be pink to light red. Yellowish brown stains, probably resulting from alteration of pyrite or glauconite grains, are scattered throughout most samples.

Between Waco (Hueco) Springs fault and Comal Springs fault the Buda forms a resistant cap on low hills. Weathered outcrops are generally covered with a thin reddish brown soil and rounded cobbles of limestone. The formation supports a dense population of juniper, elm, and oak. A complete section of the Buda is exposed along Bat Cave Road between Blank Ranch fault and Hoffman Ranch fault (pl. 1).

Where exposures are limited, it is difficult to distinguish the Buda from resistant limestone of the Georgetown or Austin. Commonly the Buda is less glauconitic and appears less iron-stained than the Georgetown, whereas it contains more fossil gastropods than the Austin.

The lower and upper boundaries of the Buda are conformable and disconformable, respectively. The transition with the underlying Del Rio Clay, where exposed, is a zone of soft, punky, chalky, pulverulent limestone. The contact with the overlying recessive Eagle Ford Shale is sharp and conspicuous. An iron-stained corroded surface at the top of the Buda apparently represents a disconformity persistent throughout central and south-central Texas (Adkins, 1933, p. 423; Martin, 1967, p. 290).

Numerous molluscs, foraminifers, ostracods, serpulids, echinoid spines, bryozoans, and calcispheres occur throughout. Locally, solitary corals and green algae may be found in the unit. The following fossil organisms were identified:

Pelecypoda:
- *Texigryphaea* sp.

Gastropoda:
- *Turritella* sp.
- *Nerinea* sp.

Foraminifera:
- *Textularia* sp.
- *Dentalina* sp.
- *Globigerina* sp.

Gulf Series

Hill (1887, p. 298) first applied the term "Gulf Series" to the uppermost provincial time-rock unit in the Cretaceous System of Texas. It includes all strata above the base of the Woodbine Group and below the base of the Midway Group (Adkins, 1933, p. 400). Adkins (1933, p. 401) stated that the boundary between the Gulf and underlying Comanche Series is unconformable.

In north Texas the Gulf Series is divided into five groups: 1) Woodbine, 2) Eagle Ford, 3) Austin, 4) Taylor, and 5) Navarro. The Woodbine and Navarro Groups are not present in Bat Cave quadrangle. Because the stratigraphic intervals representing the other three groups are thin, lithically distinct, and poorly exposed, they have been mapped as formations and have not been subdivided.

Eagle Ford Shale.--Hill (1887, p. 296-298) recognized the correct stratigraphic position of these "fish-bearing shales," and proposed the term "Eagle Ford Shale" for outcrops near Eagle Ford in Dallas County.

Within the thesis area the Eagle Ford consists of approximately 20 feet of tan to light orange, thin bedded, calcareous clay, interbedded with more resistant, light yellowish brown, flaggy limestone beds, from one to four inches thick. The limestones are well sorted, silty, fossiliferous, intraclastic calcarenites, exhibiting scour features, horizontal current laminations, and low-angle cross stratification. Mudcracks are visible locally on the upper surfaces of the flagstones (fig. 8), which commonly contain oysters (*Exogyra* sp.), ostracods, foraminifers, fish bones and teeth, and fragments of Inoceramus sp.

Prolonged weathering of the Eagle Ford on flat or gently rolling terrain produces a rich, dark brown soil. Where it has not been cultivated, mesquite flourishes. In at least two locations ranchers have constructed small water tanks within the impervious clay.

Even on relatively steep slopes the Eagle Ford is usually covered. Only float blocks of more resistant limestone flags remain as an indication of its presence. Because the Eagle Ford is much less resistant than underlying Buda Limestone, a distinct slope-break, which can be traced on air photos, forms at their boundary. The best exposure of the unit is in a small quarry-pit near the Garden Ridge housing development, east of Bat Cave Road about one mile north of its junction with FM 1337.

Both the lower and upper boundaries of the Eagle Ford are believed to be regionally unconformable (Adkins, 1933, p. 423, 440). An iron-stained corrosion surface occurs at the top of the underlying Buda Limestone. The significance of this feature may be debated, but it probably indicates that at least a short period of non-deposition occurred prior to deposition of the Eagle Ford. Although in other parts of south-central Texas the Austin-Eagle Ford contact is reported to be disconformable (DeCook, 1956, p. 32), in Bat Cave quadrangle the contact between the two appears to be conformable and gradational.

Austin Limestone.--Shumard (1860) first used the term "Austin Limestone" in referring to the stratigraphic interval containing white, chalky limestone exposed at Austin, Travis County, Texas. Within Bat Cave quadrangle the Austin caps a few hills north of Comal Springs fault, but occurs only in the subsurface south of it. George (1952, p. 26) reported that water wells in Comal County, south of the fault, have penetrated about 150 feet of strata with Austin lithology. Only the lower 80 feet of the formation crops out within the thesis area.

Two to three foot thick beds of moderately resistant, chalky, pelecypod shell-fragment biomicrite, alternating with a few, thin bedded, poorly indurated, chalky, argillaceous, fossiliferous micrites, characterize the Austin in the map area. Finely disseminated, silt-size glauconite and pyrite grains comprise up to five percent of most beds in the unit. Fresh exposures appear light yellowish gray to pale yellowish orange, but are light gray to medium gray when weathered.

Weathering has obliterated the original depositional texture and has formed a thick caliche crust on most Austin outcrops in the quadrangle. A thick black soil, which supports dense stands of juniper and live oak, develops in areas of low relief.

The contact of the Austin Limestone with the underlying Eagle Ford Shale appears to be gradational in the study area. The depositional contact with the overlying Taylor Clay is not exposed. However, Stephenson (1937, p. 135-136) reported that Taylor unconformably overlies Austin near New Braunfels.

Numerous pelecypods, echinoids, ostracods, and foraminifers occur in the Austin Limestone. The following fossils were collected and identified:

Echinoidea:
Hemiaster texanus Römer

Pelecypoda:
Pycnodonte aucella (Römer)
Exogyra laeviscula Römer
Inoceramus subquadratus Schlüter

Ammonoidea:
Turrilites sp. cf. *scheuchzerianus* Bosc
Prionocyclus n. sp.

Taylor Clay.--The name "Taylor Marls" was first applied to this stratigraphic interval by Hill (1892). The type section is along the Colorado River in Travis County, east of Austin.

In Bat Cave quadrangle an estimated maximum of 50 feet of Taylor Clay underlies gently rolling farm land south of Comal Springs fault, where a thick, black soil is extensively cultivated. Where it is not tilled, grass and mesquite flourish. A poor exposure of Taylor occurs in a Missouri-Pacific railroad cut near the southern boundary of the quadrangle. At this locality tan, poorly indurated, calcareous clay crops out.

One small outcrop of the Taylor is north of Comal Springs fault along the west side of Caverns Road about 150 yards north of its intersection with Bat Cave Road (fig. 9). Very pale orange, indistinctly bedded, calcareous clay, containing _Baculites_ sp., is exposed in the middle of a graben complex south of Waco (Hueco) Springs fault. This may be the first reported occurrence of strata with Taylor lithology (probably Pecan Gap equivalent) north of the Balcones Escarpment (Keith Young, oral communication).

Quaternary System

Alluvium.--Poorly sorted, clay to boulder-size limestone and chert detritus has been deposited along the courses of Cibolo and Dry Comal Creeks as relatively thick point-bar deposits along the inside of meanders. Pebble and cobble-size limestone fragments are typically rounded and of low sphericity. Flat pebbles may show down-current imbrication. The alluvium is poorly consolidated and has variable thickness, locally reaching a maximum of 30 feet. Most of it is probably Pleistocene.

Colluvium.--A few, large blocks of Edwards Limestone, ten feet or more in length, have slumped down the steep valley walls of Cibolo and Dry Comal Creeks. Presumably, slope failure has resulted from undercutting during periods of high velocity flow in the stream channels.

Figure 8. Mudcracks on top surface of a limestone bed in the Eagle Ford Shale.

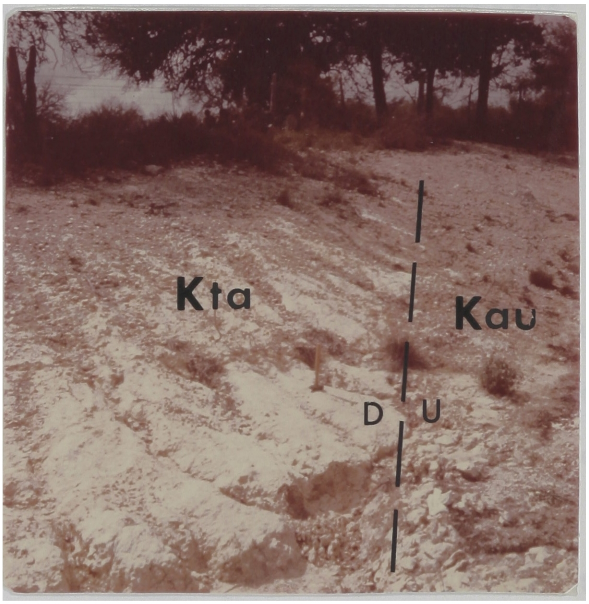


Figure 9. Taylor Clay (Pecan Gap) in fault contact with Austin Limestone. Westward view along Caverns Road about 200 yards from its intersection with Bat Cave Road.

STRUCTURAL GEOLOGY

Regional Dip

North of Comal Springs fault in the Edwards Plateau, strata dip southeast at a rate of 15 to 20 feet per mile (George, 1952, p. 33). South of the fault beneath the Gulf Coastal Plain, the dip increases to 100 to 150 feet per mile (Arnow, 1963, p. 22).

Local Dip

Adjacent to faults dips of up to 45° are common, due principally to frictional drag accompanying displacement along the fault. However, at several places, strata on the downthrown side of a fault dip northwest into the fault plane (fig. 10). This phenomenon has been observed in other parts of the Balcones fault zone and Gulf Coast and has been termed "reverse drag" or "reverse dip" (Bills, 1957, p. 62).

Locally, in strata of the Edwards Group, small folds have formed that do not appear to be associated directly with faults (fig. 11). The folds appear to have been produced by solution and collapse of underlying limestone beds. The dip of limbs of these structures normally does not exceed ten degrees.

Figure 10. Glen Rose dolomite beds on downthrown (southeast) side of Zaccaria Ranch fault. Beds dip northwest toward the fault which is hidden by trees on left side of photo. Northeast view across Cibolo Creek about 0.3 miles northwest of where FM 1863 crosses the creek.

Figure 11. Small anticlinal fold in beds of the Person Formation. Photo was taken on southwest side of Servtex Materials Company quarry in southeastern part of the quadrangle.

Joints

Numerous joint sets have been produced by northwest-southeast tensional stresses causing Balcones faulting. Joints in the Edwards are nearly vertical, whereas those in the Glen Rose Formation dip 60 to 70 degrees. A plot of 112 joint orientations shows a primary mode between N. 50° E. and N. 65° E. and a secondary mode between N. 40° W. and N. 50° W. These two modes are parallel and perpendicular, respectively, to the surface traces of major faults in the area. Although these measurements may not be statistically significant, they compare favorably with those reported by Muehlberger and Kurie (1956) and Dunaway (1962) during their investigations of fracture patterns in Travis County.

Faults

Bat Cave quadrangle straddles the Balcones fault zone. Strata in the area have been displaced 1,200 feet downward to the southeast by movement along gravity faults of this system. Five major faults and 86 minor faults have been mapped (pl. 1). The term major fault, as used in this thesis, refers to a fracture along which strata have been displaced, vertically, at least 100 feet. A minor fault has a throw of less than 100 feet.

Fault trends were measured by overlaying a grid of three inch squares on the geologic map of the quadrangle (pl. 1), and then, using a protractor to determine the approximate strike of each fault in a given grid square. Finally, this data was plotted on two rose diagrams divided into ten degree sectors (fig. 12). All major fault trends are concentrated in the northeast quadrant, 60 percent being between N. 40° E. and N. 60° E. The strikes of minor faults are bimodally distributed and much more variable, only 28 percent being between N. 40° E. and N. 60° E. The two modes occur in the N. 50° E. to N. 60° E. and the N. 80° E. to N. 90° E. sectors.

Major Faults

All five major faults in the area are normal (gravity) faults, downthrown to the southeast. All form distinct, easily traced lineations on aerial photographs. Although their fault planes are everywhere covered, it can be inferred that they have steep dips because their surface traces are relatively straight through rugged terrain. All but one of the major faults have been named and described by George (1952, p. 28-32).

Hidden Valley fault transects the quadrangle's northwestern corner, striking N. 40° E. It has a throw of about 130 to 140 feet. Alluvium eroded from an obsequent fault-line scarp along the southeast side covers the outcrop of the fault. Therefore, its precise location can only be inferred.

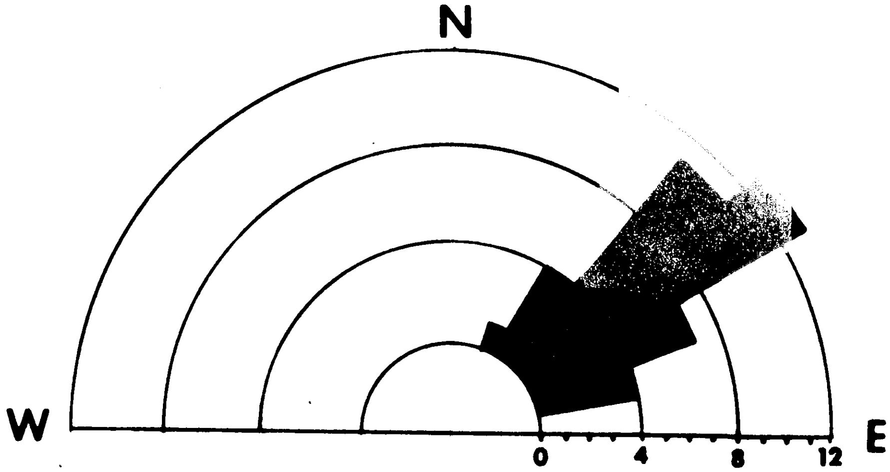


Figure 12a. Rose diagram showing orientations of major faults measured from the geologic map (plate 1).

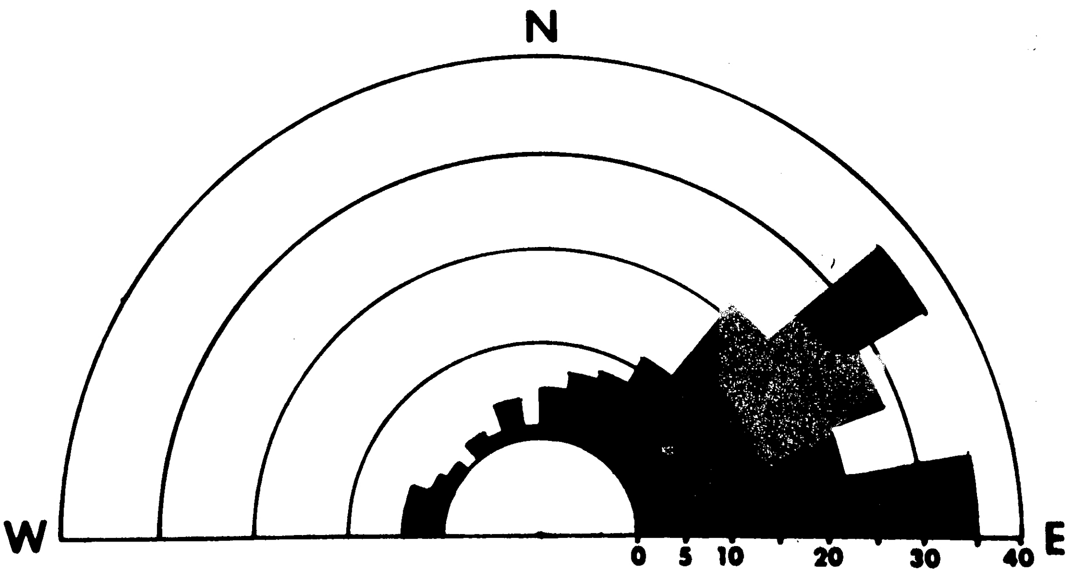


Figure 12b. Rose diagram showing orientations of minor faults measured from the geologic map (plate 1).

The major fault, herein named Zaccaria Ranch fault, is approximately 3,000 feet to the southeast of, and parallel to Hidden Valley fault. Across the fault vertical displacement of the Glen Rose-Walnut contact averages 120 feet. For most of its length the fault follows a narrow steep-sided valley on the Zaccaria Ranch. It probably joins Hidden Valley fault southwest and northeast of the quadrangle. Along the downthrown side, strata of the Glen Rose Formation dip four degrees northwest toward the fault plane, which has been covered by alluvium (fig. 10).

Bat Cave fault trends approximately N. 60° E., diagonally across the map area, from a point about midway along the western edge to a point 2,800 feet south of the northeastern corner. The throw varies from 200 feet near where it crosses FM 1863 to 250 feet, south of Natural Bridge Caverns. A resequent fault-line scarp has formed along the upthrown, northwest side.

Waco (Hueco) Springs fault, which transects the central portion of the area, exhibits the most irregular surface trace of the major faults. It strikes N. 85° E. between Cibolo Creek and Bat Cave Road, then nearly parallels Schoental Road, averaging N. 60° E. to where it leaves the quadrangle. Bed displacement ranges from 120 feet, approximately one mile southwest of where the fault crosses FM 1863, to 250 feet at a point west of Cibolo Creek near Barrett Industries quarry, where the Del Rio Clay and Kainer Formation are in fault contact. Differences in throw result from development of numerous antithetic, synthetic, and cross faults along the downthrown side.

Comal Springs fault strikes N. 60° E. across the quadrangle's southeastern part, paralleling FM 1337 for most of its length. Throw decreases from 400 feet near Servtex quarry, where the Taylor and Person Formations are in fault contact, to 200 feet, where the fault crosses the quadrangle's southern boundary. The reduced displacement is the result of two minor cross faults which intersect Comal Springs fault on the upthrown side at an angle of 30°. Limestone of the Edwards Group exposed in quarries near this major fault is typically brecciated and sheared as a result of frictional drag accompanying movement along the fault plane. A prominent resequent fault-line scarp, the Balcones Escarpment, has formed along the upthrown, north side.

Minor Faults

The large number of minor antithetic, synthetic, and cross faults associated with major faults are not necessarily downthrown to the southeast. Generally, minor faults display more irregular surface traces, probably because their fault planes are covered or dip at lower angles than those of major faults.

Fault density is greatest between Waco Springs fault and Comal Springs fault. This can be partly attributed to the presence of a thick sequence of competent, brittle rock of the Edwards Group beneath the surface. In this zone minor faults commonly bifurcate and intersect at acute angles, forming very complex patterns, especially in the south-central part of the area between Bracken fault and Blank Ranch fault, and through the central portion along the down-thrown southeastern side of Waco Springs fault.

Because of the complexity of faulting it is not feasible to describe, individually, all minor faults. Therefore, only a few of the more unusual and significant ones will be discussed and named.

Surface traces of <u>Hoffman Ranch fault</u> and <u>Blank Ranch fault</u> form a canoe-shaped pattern in the south-central part of the map area near the junction of Schoental Road with Bat Cave Road. Both faults trend northeast for about three miles and have throws of approximately 65 feet. The fault block between them is upthrown. Comparison of the curvature of their fault traces with the topography leads to the conclusion that Hoffman Ranch fault and Blank Ranch fault dip southeast and northwest, respectively, and are, therefore, reverse faults. Possibly, local compressional and shear stresses associated with differential rates and amounts of movement along Hueco Springs and Comal Springs faults could have produced local reverse faulting. However, if the fault planes of the two minor faults are curved, these conclusions might not be valid.

Herholzer Ranch fault originates between Bat Cave Road and Waco Springs fault, and strikes east-west for three miles through the quadrangle's south-central part, and N. 55° E. through the east-central part. The fault has displaced strata a maximum of 80 feet, vertically, and for most of its length, is downthrown to the southeast. Where the fault changes trend, an outlier of Buda Limestone and Del Rio Clay has been preserved in a small graben formed by collapse along the downthrown side.

Tschoepe Ranch fault is an antithetic fault formed in response to structural adjustment subsequent to movement along Waco Springs fault. It forms the southeast side of a graben complex in the east-central part of the map area along the downthrown side of the major fault. The fault's surface trace strikes an average of N. 50° E. and appears to be little affected by terrain, indicating that the fault plane dips steeply. About 300 yards west of Schoental Road it appears to terminate against an east-west cross fault. Beds along the fault have been downthrown to the northwest a maximum of 70 feet.

Zuercher Ranch fault trends east-west for more than 6.5 miles through the northern one-third of the quadrangle.

It connects Bat Cave fault and Zaccaria Ranch fault. The fault's surface trace is relatively straight and smooth. Because resistant limestones crop out on both sides of the fault, it produces only a subtle lineation on air photos. Strata along the southeast side have been uniformly displaced 60 feet downward.

Ohlrich Ranch fault, which is nearly parallel to, and 1,000 to 1,500 feet north of Zuercher Ranch fault, forms the northern side of an upthrown horst block. The contact between the Walnut and Kainer Formations is as much as 40 feet lower on the north side of the fault, which persists for about 3.5 miles from the quadrangle's northeastern corner to where it "dies out" in the north-central part.

ECONOMIC GEOLOGY

Limestone and Dolomite Resources

Large amounts of limestone and dolomite, suitable for commercial use, are available within the Edwards Group in Comal and adjacent counties along the Balcones fault zone. Rodda _et al_. (1966, p. 18-20) estimated the reserves within the Kainer, Person, and associated formations of Comal County as 86 billion short tons of limestone and 1.34 billion short tons of dolomite, _i.e._, containing greater than 10 percent MgO.

Bat Cave quadrangle should be particularly attractive for commercial exploitation of carbonate rock resources. Extensive high-calcium limestone outcrops of the Edwards Group are within a few miles of the Missouri-Pacific, and Missouri-Kansas-Texas railroads and transportation costs to nearby markets in San Antonio would be minimal.

Limestone is presently quarried in the southeastern part of the quadrangle, just northeast of FM 1337, by Servtex Materials Company, and by Barrett Industries in the southwestern part, two miles northwest of FM 2252. Hard, durable, high-calcium limestone from the Person Formation in the Servtex quarry is used for aggregate, base materials, rip-rap, ballast, fluxstone, agricultural lime, fillers, and for chemical and industrial processes (Rodda _et al_., 1966, p. 29).

The upper part of the Kainer Formation and the Doctor Burt Member of the Person Formation are a source of crushed stone in the Barrett Industries quarry.

Ranchers obtain material for local use on private roads by quarrying moderately soft, chalky or marly limestone from the Austin or Glen Rose Formations, or from the Doctor Burt Member of the Person Formation. Flagstone from the Eagle Ford Shale has been used as building-stone at the Garden Ridge housing development.

For a more comprehensive discussion of the limestone and dolomite resources of the San Antonio-New Braunfels area, the reader should refer to Rodda _et al_. (1966).

Groundwater Resources

Within Bat Cave quadrangle groundwater is obtained from the Glen Rose Formation and the Edwards Group. These nonhomogeneous aquifers effectively transmit large volumes of water principally as a result of solution enlargement of interconnected fractures (Sayre and Bennett, 1942). This secondary porosity and permeability may be exceedingly variable over short distances (Pettit and George, 1956, p. 45-49). Beds of limestone and dolomite with well-developed, honeycomb-type, vugular porosity provide the greatest storage. Near major faults, where fractures are most numerous, networks of solution channels are best developed, permitting groundwater to move freely with only small losses of head (Sayre and Bennett, 1942; Arnow, 1963, p. 28-30). Well yields tend to be highest on the downthrown side and within several hundred yards of major faults.

Aquifers

Very little data is available for Bat Cave quadrangle concerning water-bearing units below the Upper Glen Rose. Investigations by George (1952) and Rhoades and Guyton (1955) in Comal County, and by Reeves (1967) in Kendall County suggest that moderate amounts of fresh to slightly saline water probably could be obtained from massive fossiliferous limestone in the Lower Member of the Glen Rose Formation, and from the Hensel Sandstone and Cow Creek Limestone of the Pearsall Formation. However, penetration of the Pearsall in the northern part of the quadrangle would require well depths of 1,000 feet or greater. When drilling and pumping costs are weighed against the probability of only moderately increased yields, it is doubtful that it would be worthwhile to drill wells below the base of the Glen Rose Formation in this area (Richard Reeves, 1971, oral communication).

North of Bat Cave fault most wells obtain small amounts of fair to poor quality water from the lower part of the Upper Member of the Glen Rose Formation (fig. 13). Yields from six inch diameter wells rarely exceed 10 gallons

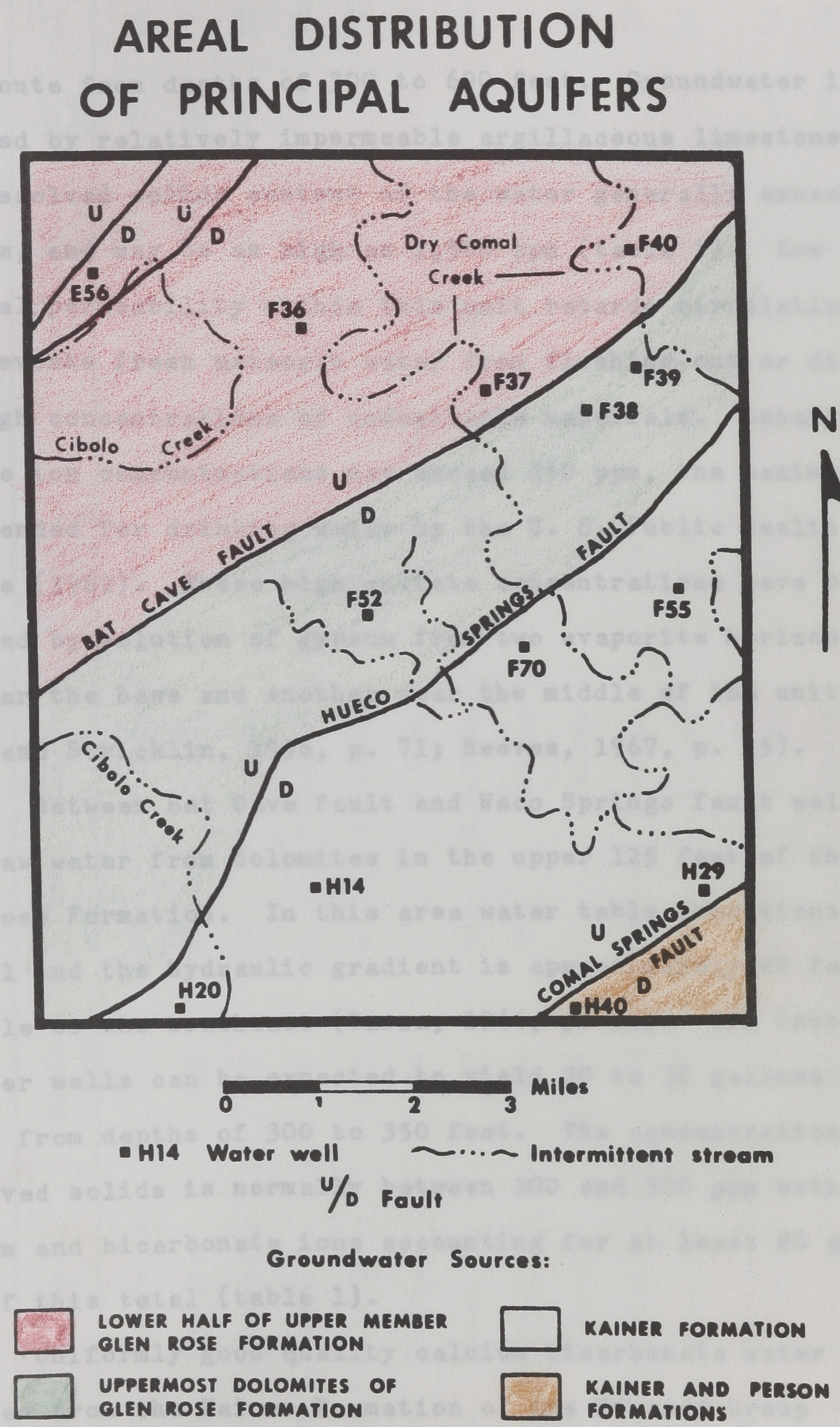

AREAL DISTRIBUTION
OF PRINCIPAL AQUIFERS
U
D
E56
F36
Dry Comal
Creek
F40
F39
F37
F38
Cibolo Creek
BAT CAVE FAULT
HUECO SPRINGS FAULT
F52
F55
F70
Cibolo Creek
H14
H29
H20
COMAL SPRINGS FAULT
H40
N
0 1 2 3 Miles
H14 Water well
Intermittent stream
U/D Fault
Groundwater Sources:
LOWER HALF OF UPPER MEMBER GLEN ROSE FORMATION
UPPERMOST DOLOMITES OF GLEN ROSE FORMATION
KAINER FORMATION
KAINER AND PERSON FORMATIONS

Figure 13.

per minute from depths of 300 to 600 feet. Groundwater is confined by relatively impermeable argillaceous limestones. The dissolved solids content of the water generally exceeds 400 ppm, and may be as high as 1,500 ppm (table 1). Low vertical permeability within this unit retards circulation and prevents fresh meteoric water from flushing-out or diluting high concentrations of undesirable materials. Locally, sulfate ion concentrations may exceed 250 ppm, the maximum recommended for drinking water by the U. S. Public Health Service (1962). These high sulfate concentrations have been produced by solution of gypsum from two evaporite horizons, one near the base and another near the middle of the unit (Lozo and Stricklin, 1956, p. 71; Reeves, 1967, p. 15).

Between Bat Cave fault and Waco Springs fault wells withdraw water from dolomites in the upper 125 feet of the Glen Rose Formation. In this area water table conditions prevail and the hydraulic gradient is approximately 20 feet per mile to the southeast (Garza, 1966, p. 22). Six inch diameter wells can be expected to yield 20 to 30 gallons per minute from depths of 300 to 350 feet. The concentration of dissolved solids is normally between 300 and 500 ppm with calcium and bicarbonate ions accounting for at least 80 percent of this total (table 1).

Uniformly good quality calcium bicarbonate water is obtained from the Kainer Formation of the Edwards Group

Table 1. Chemical analyses of water from representative wells, concentrations in parts per million (modified after Pettit and George (1956))

Well	Owner	Depth (feet)	Diameter	Source	Total Dissolved Solids	Ca^{++}	Mg^{++}	HCO_3^-	$SO_4^=$	Cl^-
E56	Hitzfelder	381	6"	U.G.R.	911	-	-	67	590	13
F36	Zeurcher	535	6"	U.G.R.	593	122	48	293	260	9
F37	Westerfer	507	5"	U.G.R.	-	-	-	282	1400	12
F38	Tonne	320	-	U.C.R.Dol.	239	59	17	281	0	11
F39	Ohlrich	265	6"	U.G.R.Dol.	298	-	-	348	0	8
F40	Ohlrich	350	6"	U.G.R.	741	212	29	329	295	43
F52	Wuest	320	6½"	U.G.R.Dol.	480	117	20	314	6	35
F55	Vogel	300	6"	Kainer	235	80	7	244	0	25
F70	Krause	288	6"	Kainer	130	34	6	79	31	15
H14	Gerhardt Est.	326	6"	Kainer	241	-	-	275	0	10
H20	Schaeffer	300	4"	Kainer	233	33	28	195	32	28
H29	Servtex Materials Co.	160	15"	Kainer	282	82	12	290	7.7	11
H40	Schneider	192	6"	Person	278	60	12	250	20	30

between Waco Springs fault and Comal Springs fault. In this area groundwater is generally unconfined, but may be locally confined and under a small amount of artesian pressure. The hydraulic gradient is approximately five feet per mile to the southeast (Garza, 1966, p. 22). Most wells encounter water at depths of 150 to 300 feet and can produce in excess of 50 gallons per minute. Water from the Kainer rarely contains more than 300 ppm total dissolved solids.

In the quadrangle's southeastern corner good quality water occurs under artesian conditions in the Person and Kainer Formations of the Edwards Group. Amounts sufficient for domestic and stock use can normally be obtained from wells penetrating only the Person. Irrigation and industrial supply wells, twelve to sixteen inches in diameter, located near Comal Springs fault and penetrating nearly a complete section of the Edwards Group, may yield in excess of 1,500 gallons per minute (Rettman, 1969, p. 15).

Approximately three miles south of the quadrangle the total dissolved solids content of the water in the Edwards increases to values in excess of 1,000 ppm (Pettit and George, 1956, p. 77). South of this "bad water line" small amounts of hydrogen sulfide gas are frequently encountered by wells tapping the aquifer. Sulfate and chloride concentrations in the groundwater exceed 250 ppm, the maximum recommended by the U. S. Public Health Service (1962). Garza (1962, p. 38) attributes this down-dip build-up of dissolved solids to poor circulation and partial stagnation of the water in an area of lower permeability.

Direction of Flow

North of Comal Springs fault contours on the potentiometric surface trend northeast-southwest, and the general direction of groundwater movement is southeast. However, locally, there can be considerable variation in flow direction within these nonhomogeneous aquifers (Garza, 1962, p. 9). Water-level data from Pettit and George (1956) shows only small head losses across major faults, indicating good hydraulic connections between fault blocks.

South of Comal Springs fault groundwater flows northeast to Comal Springs in New Braunfels, where it discharges at an average rate of 124,000 gallons per minute (Garza, 1966, p. 16, 18).

Recharge

Groundwater reservoirs north of Comal Springs fault are recharged primarily by influent seepage from Cibolo and Dry Comal Creeks, which flow only after periods of heavy rainfall (George, 1952, p. 56-60). Water losses are particularly high where these streams cross Edwards outcrops near major faults. Pettit and George (1956, p. 36) estimated that Cibolo Creek contributes an annual average 58,000 acre-feet of water, 92 percent of its total yearly flow, to aquifers in the Bexar and Comal County area. Dry Comal Creek contributes an estimated 24,800 acre-feet, 77 percent of the computed runoff within its drainage basin.

South of Comal Springs fault the Edwards Group is in the subsurface, and greatest recharge is by underflow from Bexar County (Garza, 1962, p. 34). Arnow (1963, p. 28) estimated that underflow from Bexar County to Comal County is between 220,000 and 260,000 acre-feet per year.

Within the past ten years two small flood control dams have been built across tributaries of Dry Comal Creek in an effort to increase recharge to the Edwards aquifer. Water ponded behind Eikel-Blank Dam following a heavy rainfall will disappear within five days (Herman Blank, 1970, oral communication).

The U. S. Army Corps of Engineers (1965) investigated a prospective dam-site on Cibolo Creek near Bracken Bat Cave. After studying the geology and hydrology of the immediate area they concluded that increased recharge resulting from construction of a dam would not be sufficient to justify the cost.

Discharge

Inasmuch as there are no major springs within the quadrangle and because only a relatively few small capacity wells withdraw water from the aquifers, discharge probably does not exceed recharge. Largest withdrawals occur in the southeastern corner at the Servtex Materials Company quarry, where well H29, the only industrial capacity well in the map area, produces over one million gallons per day (George, 1952, p. 42).

A P P E N D I X

Introduction to Measured Section Descriptions

The locations of the four measured sections contained in the appendix are noted on plate 1 (in pocket). In addition, brief descriptions of the locations are included at the beginning of each section.

The following rock properties, where determinable, are listed for each unit in this order: 1) bed thickness, 2) general rock name, 3) Folk classification name, 4) allochemical constituents, 5) fossil content, 6) structures, 7) porosity, 8) hardness, 9) bedding characteristics, and 10) fresh and weathered color.

General rock name: The terms limestone, recrystallized limestone, dolomitic limestone and dolomite are used to indicate the gross lithology of each unit in a measured section.

limestone - applies to rocks containing greater than 90% calcium carbonate and displaying original depositional texture with allochems, micrite, and sparite relatively little altered.

recrystallized limestone - contains greater than 90% $CaCO_3$ but original depositional texture has been destroyed by diagenetic processes.

dolomitic limestone - the mineral "dolomite" comprises greater than 10% but less than 50% of the rock.

dolomite - rhombic crystals of "dolomite" comprise greater than 50% of the rock, which usually has saccaroidal texture and is moderately friable when weathered.

Folk classification name: Wherever possible each rock unit is described and classified following the method proposed by R. L. Folk (1959, 1962). However, "muddy" is used instead of "poorly washed," and the term "pellet" refers to any structureless allochemical constituent that is less than 0.5 mm in diameter, shows no evidence of transport, and appears to be from an organic source.

Allochemical constituents: The Wentworth scale is used to describe allochem grain size. Rounding and sorting are determined by using methods discussed by Folk (1962, p. 80-81). Terms describing dolomite crystal size are from Folk's grain size scale for carbonate rocks (1962, p. 74).

Porosity: An estimate is made of the approximate amount of porosity in each rock unit. Porosity in limestone is normally secondary and vugular. Dolomite usually contains a small amount of intergranular porosity in addition to some leached porosity.

Hardness: The relative amount of consolidation or induration of each unit is indicated by using the following scale:

1. very soft
2. soft
3. moderately soft
4. moderately hard
5. hard
6. very hard

Bedding characteristics: The following terms are used in the description of each unit to indicate bedding thickness and character:

- thin bedded - less than 2" thick
- medium bedded - between 2" and 1' thick
- thick bedded - greater than 1' thick
- massive - no visible bedding planes between the upper and lower contacts of the unit
- nodular - irregular bedding planes, weathered surface appears lumpy.

Fresh and weathered color: The Geological Society of America Rock Color Chart is used to determine rock colors in the field and in the laboratory.

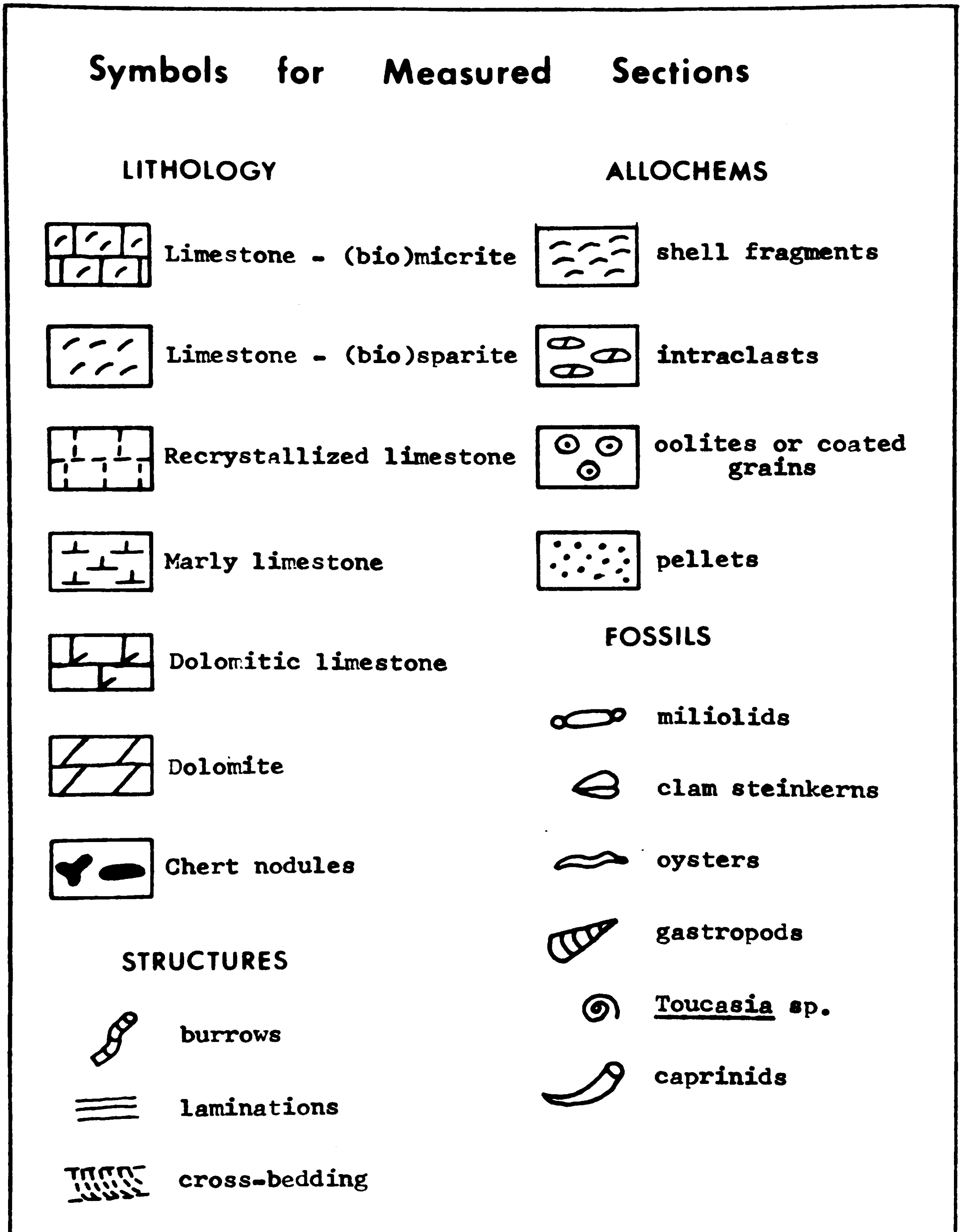

Symbols for Measured Sections
LITHOLOGY
Limestone - (bio)micrite
Limestone - (bio)sparite
Recrystallized limestone
Marly limestone
Dolomitic limestone
Dolomite
Chert nodules
STRUCTURES
burrows
laminations
cross-bedding
ALLOCHEMS
shell fragments
intraclasts
oolites or coated grains
pellets
FOSSILS
miliolids
clam steinkerns
oysters
gastropods
Toucasia sp.
caprinids

Figure 14.

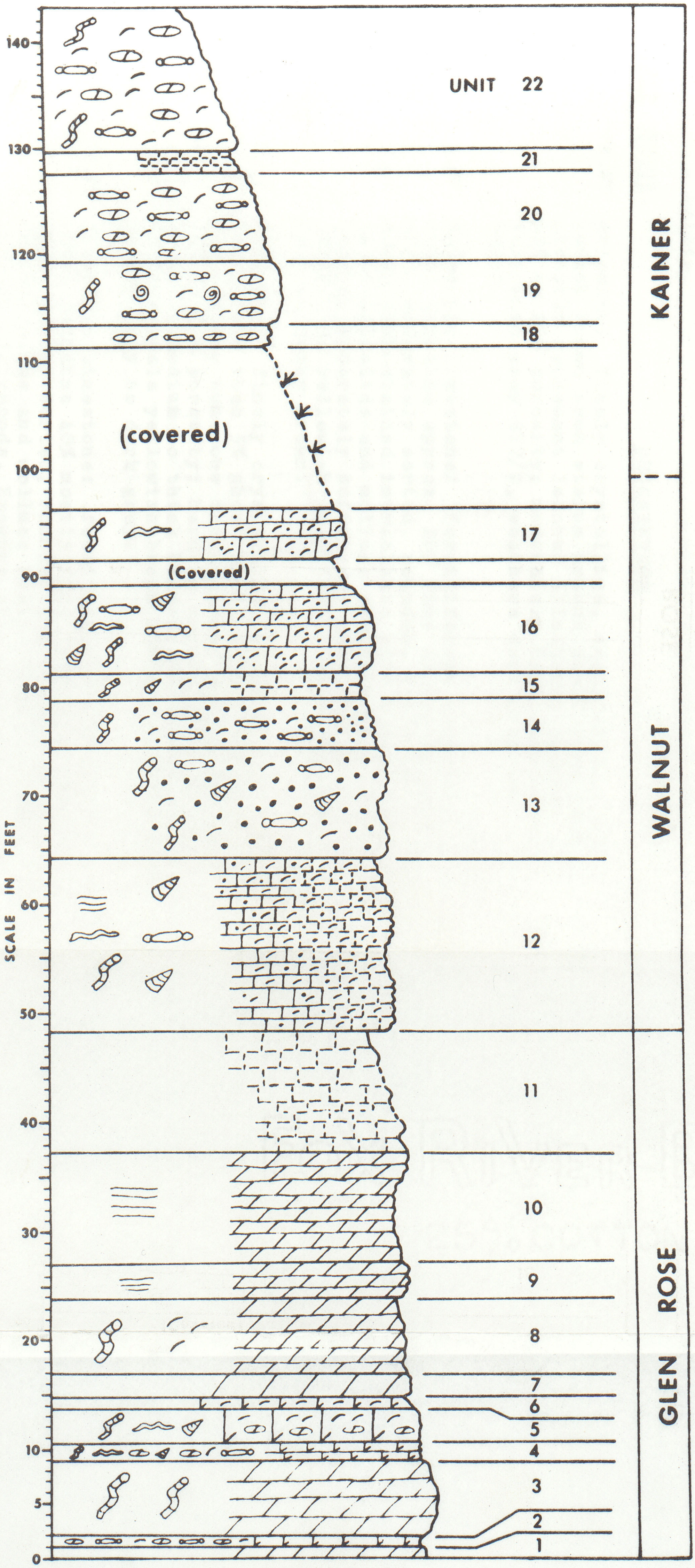


Figure 15. Measured Section One

Measured Section One

Location: The section was measured in a re-entrant in cliffs along the south side of Cibolo Creek on the Arnold Reeh Ranch, approximately 0.4 miles west-southwest of his hunting cabin. Section starts at base of cliffs.

UNIT	THICK.	DESCRIPTION
1	1.0'	Dolomite: finely crystalline, saccaroidal; yellowish brown iron stains around small vugs that probably represent leached allochems; approx. 15% to 20% porosity; moderately hard; massive; yellowish gray 5Y7/2, weathers dark gray to black.
2	1.0'	Dolomitic limestone: fossiliferous intramicrite; contains approx. 20% fine to medium sand-size, moderately sorted, rounded, yellowish brown iron-stained intraclasts with a few scattered miliolids and mollusc shell-frags.; thin bedded; moderately soft; very pale orange 10YR8/2 to yellowish gray 5Y8/2, weathers dark gray to dusky brown.
3	7.0'	Dolomite: finely crystalline, saccaroidal; contains less than 5% ghost shell-frag. allochems, unoriented; numerous iron-stained burrow-fills; 15% to 20% porosity; hard to moderately hard and friable; medium to thick bedded; yellowish gray 5Y7/2 to pale yellowish brown 10YR7/2, weathers medium gray to dark gray.
4	1.5'	Dolomitic limestone: fossiliferous intramicrite; contains 40% mostly fine to coarse sand-size, poorly sorted, rounded intraclasts with a few miliolids and mollusc shell-fragments; gastropods, ostracods, <u>Exogyra</u> sp.; numerous burrow-fills; matrix is almost completely dolomitized; approx. 5% porosity; hard, thin bedded; yellowish gray 5Y8/1 to 5Y7/2 with scattered iron-staining, weathers dark gray to black.
5	3.2'	Dolomitic limestone: fossiliferous intramicrite; contains approx. 25% unoriented, fine to medium sand-size, moderately sorted, rounded allochems; gastropods, ostracods, <u>Exogyra</u> sp.;

UNIT	THICK.	DESCRIPTION
		abundant burrow-fills; matrix is almost completely dolomitized; 5% to 10% porosity; hard; massive; yellowish gray 5Y8/1 to 5Y7/2, weathers medium gray to dark gray.
6	1.0'	Dolomitic limestone: mollusc shell-fragment biomicrite; thin bedded; moderately hard; yellowish gray 5Y7/2, weathers medium gray.
7	2.0'	Dolomite: finely crystalline; 15-20% porosity; massive; moderately hard; yellowish brown iron stains around vugs; light olive gray 5Y6/1 weathering dark gray to black.
8	7.0'	Dolomite: finely crystalline; burrowed; few molds of pelecypod shells; 15-20% porosity; moderately hard; medium to thick bedded; yellowish gray 5Y7/2 weathering dark red to gray to black.
9	3.0'	Dolomite: finely crystalline; less than 5% yellowish brown iron-stained ghost allochems; a few faint laminations; 10-15% porosity; contains a few veinlets of sparry calcite; moderately hard; thin to medium bedded; yellowish gray 5Y7/2 weathering medium gray to dark gray.
10	10.3'	Dolomite: finely crystalline; laminations several mm thick; 15-20% porosity; moderately soft to moderately hard; medium bedded; covered with large quantities of moss; yellowish gray 5Y7/2 mottled by irregular yellowish brown iron stains (root mottling?), weathers medium gray to dark red or brown.
11	11.0'	Recrystallized limestone: coarsely crystalline; locally laminated; lower 3 feet with 20% vugular porosity, remainder of unit with some scattered vugs and solution cavities; generally poorly exposed and covered; bedding obscure; soft to moderately hard; variable color, very pale orange 10YR8/2 to grayish orange 10YR7/4.

Top of Glen Rose Formation

UNIT	THICK.	DESCRIPTION
12	16.0'	Recrystallized limestone: pelletal biomicrite; few miliolids and mollusc shell-fragments, ostracods, gastropods; burrowed; contains a few

UNIT	THICK.	DESCRIPTION
		irregular laminations; numerous solution cavities especially near the base, some as large as one inch in diameter and filled with white sparry calcite; hard; medium bedded; nodular when weathered; grayish orange 10YR7/4 (mottled) with the color becoming somewhat lighter upward.
13	10.0'	Limestone: fossiliferous pelsparite; contains mostly fine to medium sand-size, well rounded and sorted, unoriented "pellet-like" allochems; few miliolids and mollusc shell-fragments up to 1 cm, gastropods; burrowed; nonporous; very hard; medium bedded; grayish orange 10YR7/4 with some light gray N7 mottling, weathers light gray to medium gray.
14	4.5'	Limestone: fossiliferous pelsparite; contains mostly fine sand-size, well rounded and sorted, "pellet-like" allochems, many are leached and iron-stained; numerous miliolids, few mollusc shell-fragments, ostracods; nonporous; dense, very hard; medium bedded; grayish orange 10YR7/4 weathering medium to dark gray.
15	2.5'	Recrystallized limestone: very few unaltered allochems visible; few mollusc shell-fragments and some gastropod molds; burrowed; contains a few thin veinlets of sparry calcite, and a few cavities filled with coarsely crystalline sparry calcite; honeycombed; approx. 10% vugular porosity; very hard; medium bedded; grayish orange 10YR7/4 to dark yellowish orange 10YR6/6, weathers medium to dark gray.
16	8.0'	Limestone: pelletal mollusc shell-fragment biomicrite; contains 50-60% fine to medium sand-size, moderately rounded and sorted, unoriented allochems; pelecypods, gastropods, miliolids, ostracods, *Exogyra texana*; burrows filled with pellets; hard; lower 5' is massive and honeycombed, upper 3' is medium bedded and nodular when weathered; pale yellowish brown 10YR6/2 to grayish orange 10YR7/4, weathers medium to dark gray.
	2.5'	Covered interval.

UNIT	THICK.	DESCRIPTION
17	4.5'	Limestone: pelletal mollusc shell-fragment biomicrite; contains 50-60% fine to medium sand-size, moderately sorted and rounded, unoriented allochems; ostracods, a few shell-fragments up to 1 cm; 5-10% porosity; dense, very hard; lower 2.5' is massive, upper 2' is thin bedded; grayish orange 10YR7/4 with scattered reddish brown iron stains, weathers medium to dark gray.
	15.0'	Covered interval (top of Walnut Formation estimated to be three feet above the top of Unit 17).
18	2.0'	Limestone: fossiliferous intrasparite; contains mostly fine to coarse sand-size, moderately sorted and rounded, allochems oriented parallel to bedding; few mollusc shell-fragments and miliolids; recrystallized locally; less than 5% porosity; hard; medium bedded; very pale yellowish orange 10YR8/4, weathers medium to dark gray.
19	6.0'	Limestone: fossiliferous intrasparite; contains mostly fine to medium sand-size, moderately sorted and rounded, unoriented allochems; numerous miliolids, few mollusc shell-fragments, Toucasia sp.; burrowed; recrystallized locally; honeycombed, 5-10% porosity; very hard; medium to thick bedded; yellowish gray 5Y7/2 weathering to medium gray.
20	8.5'	Limestone: fossiliferous intrasparite; contains mostly sand-size, well rounded, moderately sorted, unoriented allochems; numerous miliolids, few gastropod and pelecypod shell-fragments, few rudistid molds; honeycombed; very hard; thick bedded; yellowish gray 5Y8/1 weathering to medium gray.
21	2.0'	Recrystallized limestone: 5-10% vugular porosity; hard; medium bedded; yellowish gray 5Y8/1 weathering medium gray.
22	13.5'	Limestone: fossiliferous intrasparite; contains mostly medium to coarse sand-size, moderately rounded, poorly sorted, unoriented allochems; miliolids and mollusc shell-fragments; burrowed; locally recrystallized; lower half of unit is honeycombed with up to 25% porosity, upper half

UNIT THICK. DESCRIPTION

is dense and nonporous; very hard; thick bedded; yellowish gray 5Y8/1, weathers light gray to medium light gray.

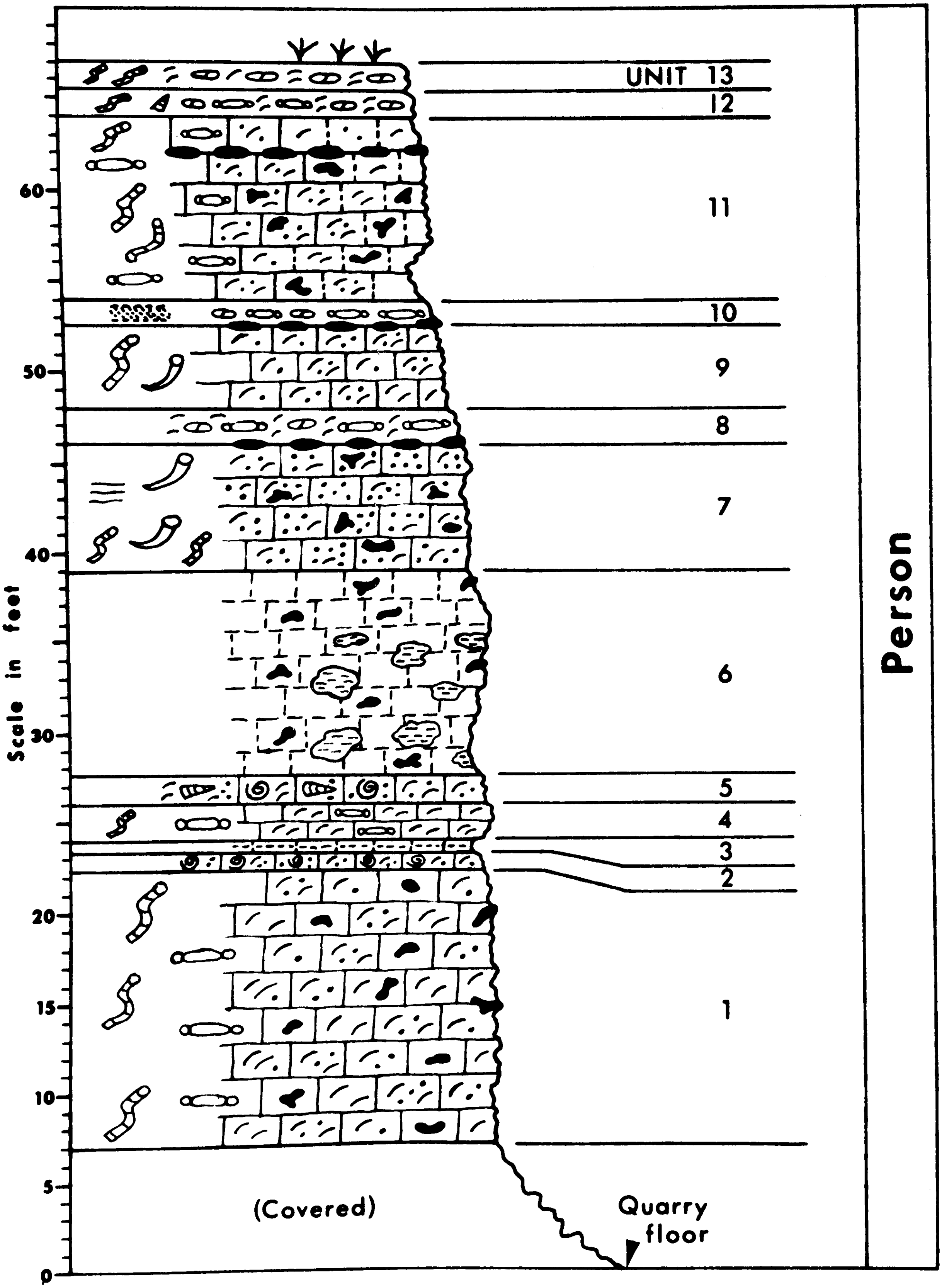


Figure 16. Measured Section Two

Measured Section Two

Location: Servtex Materials Company quarry located in the southeastern corner of the Bat Cave quadrangle just northeast of FM 1337. Section was measured up a talus pile along the east face of the quarry.

UNIT	THICK.	DESCRIPTION
1	15.3'	Limestone - partially recrystallized: pelletal mollusc shell-fragment biomicrite; contains 20% to 30% unoriented medium sand to granule-size, poorly sorted, subrounded allochems; shell frags. up to 1 cm replaced by sparry calcite and silica, few ostracods and miliolids, Pecten sp., burrowed; approx. 5% porosity, vugs locally have a dark yellowish orange 10YR6/6 drusy calcite filling; very hard, breaks with a conchoidal fracture; thick bedded; contains randomly scattered dark brown to black chert nodules which have a white to light gray patina and comprise less than 5% of the unit; mottled yellowish gray 5Y7/2 to light gray N7, weathers light olive gray 5Y6/1.
2	1.0'	Limestone: pelletal rudist shell-fragment and whole rudist biomicrudite; contains 40% to 50% unoriented, poorly sorted allochems; shell fragments up to 1 inch long, scattered miliolids, ostracods, Toucasia sp.; nonporous; very hard; massive; mottled yellowish gray 5Y7/2 to light olive gray 5Y6/1.
3	0.7'	Recrystallized limestone: contains small amount of red clay; 25% to 30% porosity; moderately soft; cavities lined with yellowish brown drusy calcite, grayish orange 10YR7/4.
4	2.0'	Limestone: mixed shell-fragment biomicrite; contains 40% to 60% unoriented, medium to coarse sand-size, poorly sorted allochems; numerous miliolids, scattered ostracods, mollusc shell-fragments replaced by sparry calcite and silica; burrowed; several spar-filled cracks observed in slab, nonporous; hard; thick bedded; yellowish gray 5Y7/2 with a reddish orange weathering crust.
5	1.7'	Limestone: pelletal rudist shell-fragment biomicrudite; contains 30% to 40% unoriented, mostly

UNIT	THICK.	DESCRIPTION
		fine to coarse sand-size, generally poorly sorted, subangular allochems; few shell-fragments up to 1" long, ostracods, Toucasia sp., steinkerns of Cerithium sp. oriented parallel to bedding; nonporous; hard; massive; light olive gray 5Y6/1 to 5Y7/2, on weathering a reddish orange crust forms.
6	11.3'	Recrystallized limestone: 20% to 30% porosity; many vugs lined with drusy calcite or filled with red clay containing small delicate fossilized vertebrate bones up to ½" long; contains scattered large irregular dark brown to black chert nodules, some as much as 12 inches in diameter, all have a white to light gray patina; hard to soft; original bedding destroyed by secondary solution; variable color, mottled, light olive gray 5Y6/1, grayish orange 10YR7/4, light brown 5YR5/6, the drusy calcite lining vugs is moderate brown 5YR4/4 to moderate yellowish brown 10YR5/4.
7	6.0'	Limestone: fossiliferous pelmicrite; contains 40% to 60% mostly fine to medium sand-size, well sorted and rounded allochems; few mollusc shell-fragments up to 1 cm, molds of caprinids; scattered burrow-fills; a few wispy laminations observed in slab; nonporous; very hard; thick bedded; irregular dark brown to black chert nodules up to 6 inches in diameter and with white to light gray patinas comprise several percent of the unit; yellowish gray 5Y8/1 to 5Y6/1, weathering light gray N7.
		A bed of dark brown to black, lenticular chert nodules, 4" to 5" thick and up to 1 foot long, occurs between Unit 7 and Unit 8. Nodules are very hard, break with a conchoidal fracture, contain silicified miliolids and mixed shell-fragments, and have a white to light gray patina.
8	2.0'	Limestone: intraclastic miliolid biosparite; contains fine to coarse sand-size, well sorted and rounded, unoriented allochems; scattered ostracods and mollusc shell-fragments; 5% to 10% porosity; hard; massive; yellowish gray 5Y8/1 to light gray N7, weathers to very light gray.

UNIT	THICK.	DESCRIPTION
9	4.5'	Limestone: pelletal mollusc shell-fragment biomicrite; 20% to 30% unoriented, fine to medium sand-size, moderately sorted, subrounded allochems; ostracods, molds of caprinids; burrowed; many shell fragments are leached and partially recrystallized; 3% to 5% vugular porosity; very hard; thick bedded; mottled, light olive gray 5Y6/1 with a reddish orange weathering crust.
		A bed of dark brown to black lenticular chert nodules occurs between Unit 9 and Unit 10. The nodules are as much as 3 inches thick and 1 foot long and have a white to light gray patina.
10	1.5'	Limestone: intraclastic miliolid biosparite; contains fine to coarse sand-size, moderately sorted, well rounded allochems, oriented parallel to bedding and at an angle to bedding; cross bedded; 5% vugular porosity; hard; massive; yellowish gray 5Y8/1 to grayish yellow 5Y8/4 nearer the surface, reddish orange weathering crust.
11	10.0'	Limestone - partially recrystallized: pelletal shell-fragment biomicrite; 20% to 30% fine to medium sand-size allochems; scattered miliolids; burrowed; nonporous; very hard and brittle; breaks with conchoidal fracture; thick bedded; less than 5% of the unit consists of scattered irregular dark brown to black chert nodules which have white patinas; light olive gray 5Y6/1 with some yellowish gray 5Y7/2 mottling, locally exhibits a reddish orange weathering crust.
12	1.5'	Limestone: fossiliferous intrasparite; contains mostly medium to coarse sand-size, well rounded, moderately sorted, unoriented allochems; numerous miliolids and mollusc shell-fragments, few gastropods, and ostracods; burrowed; 5% to 10% vugular porosity; hard; massive; very light gray N8 to light gray N7, much of surface is stained reddish orange.
13	1.5'	Limestone: muddy fossiliferous intrasparite; mostly fine to coarse sand-size, well sorted and rounded, unoriented allochems; mollusc shell-fragments up to 1 inch long, scattered ostracods; burrowed; approximately 5% porosity; hard;

UNIT	THICK.	DESCRIPTION
		massive; light olive gray 5Y6/1, weathering very light gray to light gray with light orange stains.

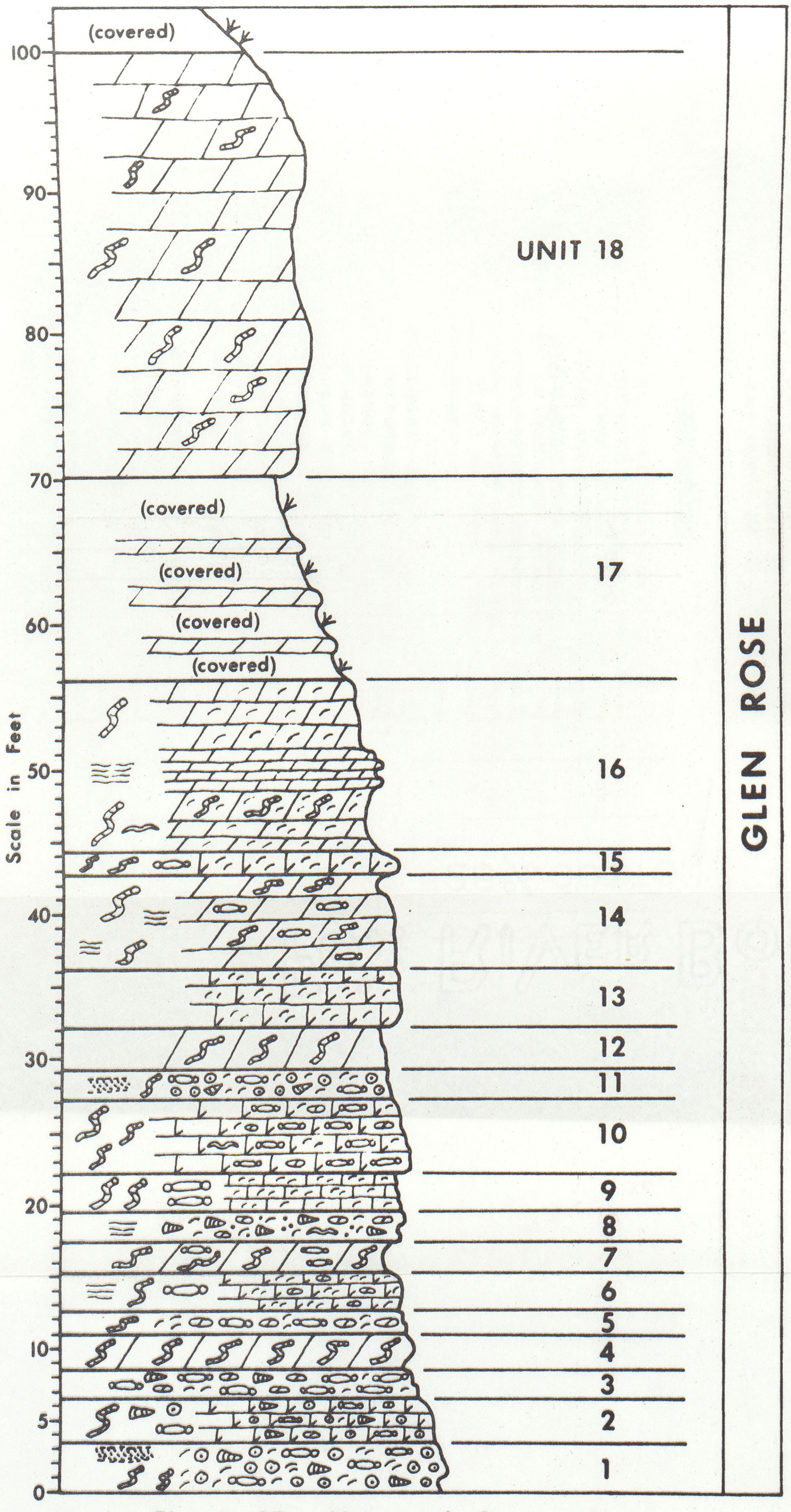


Figure 17. Measured Section Three

Measured Section Three - Zaccaria Ranch

Location: Section starts at base of cliffs on the Zaccaria Ranch along the northeast side of Cibolo Creek approximately 0.3 miles north of where FM 1863 crosses the creek.

UNIT	THICK.	DESCRIPTION
1	3.4'	Limestone: muddy, fossiliferous, coated-grain, intrasparite; contains poorly sorted, well rounded, fine to very coarse sand-size allochems; numerous miliolids and ostracods, tiny gastropod steinkerns, Textularia sp., Globigerina sp.; lower one-foot is burrowed extensively, upper one-foot is cross-bedded; nonporous; hard; thin to medium bedded; middle part nodular weathering; yellowish gray 5Y8/1 on fresh surface, weathers medium to dark gray.
2	3.0'	Dolomitic limestone: muddy, fossiliferous, coated-grain, intrasparite; contains poorly sorted, well rounded, fine to coarse sand-size, horizontally oriented allochems; numerous miliolids and gastropod steinkerns; moderate number of dolomitized burrow-fills; less than 5% porosity; bedding partially obscured by weathering, medium bedded; yellowish gray 5Y7/2 with light olive gray 5Y6/1 burrow-fills on fresh surface, weathers medium gray to black.
3	2.0'	Limestone: intraclastic miliolid biosparite; contains moderately sorted, well rounded, horizontally oriented, fine to coarse sand-size allochems; numerous miliolids with a few other types of foraminifera, mixed shell-fragments, few gastropods and ostracods; nonporous; hard; unit consists of two beds, each one-foot thick; yellowish gray 5Y8/1, weathering medium to dark gray.
4	2.6'	Dolomite: finely crystalline, saccaroidal; extensively burrowed; 10% to 15% porosity; moderately hard; massive - bedding obscure; mottled, grayish orange 10YR7/4 with light olive gray 5Y5/2 burrow-fills, weathering dark gray to black.

UNIT	THICK.	DESCRIPTION
5	1.6'	Limestone: fossiliferous intrasparite; contains poorly sorted, well rounded, unoriented, fine to very coarse sand-size allochems (a few clasts are up to ½" in diameter); numerous miliolids and mixed shell-fragments; burrowed; nonporous; hard; medium bedded; yellowish gray 5Y8/1, weathering medium to dark gray.
6	2.6'	Dolomitic limestone: intraclastic shell-fragment biomicrite; contains approximately 25% fine to coarse sand-size, horizontally oriented allochems; few ostracods and miliolids; few burrows; a few indistinct thin laminae observed in slab; moderately hard to hard; approximately 5% porosity; medium bedded; yellowish gray 5Y8/1, weathering medium to dark gray.
7	2.3'	Dolomite: finely crystalline, saccaroidal; contains a few leached miliolids; burrowed, especially near base; 10% to 15% porosity; moderately hard; massive; mottled, grayish orange 10YR7/4 to yellowish gray 5Y7/2, weathering dark gray to black.
8	2.0'	Limestone: muddy, fossiliferous intrasparite; contains poorly sorted, rounded, fine to very coarse sand-size, horizontally oriented allochems; ostracods, oyster shell-fragments, numerous tiny gastropod steinkerns, pellets; approximately 5% porosity; very hard, resistant; blocky weathering profile, medium bedded; yellowish gray 5Y7/2, weathering dark gray.
9	2.6'	Limestone: mixed shell-fragment biomicrite; contains miliolids, ostracods; numerous burrow-fills; nonporous; hard; medium bedded; yellowish gray 5Y8/1, weathers dark gray.
10	5.0'	Dolomitic limestone: muddy, intraclastic miliolid biosparite; contains well rounded and sorted, fine to coarse sand-size, unoriented allochems; ostracods and oyster shell-fragments; numerous partially dolomitized burrow-fills; nonporous; hard; medium bedded; yellowish gray 5Y8/1 with scattered yellowish brown iron-stained allochems and light olive gray 5Y6/1 burrow-fills.

UNIT	THICK.	DESCRIPTION
11	2.0'	Limestone: muddy, fossiliferous, coated-grain intrasparite; contains poorly sorted, rounded, medium to very coarse sand-size, oriented allochems; miliolids, a few ostracods and small gastropod steinkerns; cross-bedding visible in the slab; scattered dolomitized burrow-fills; nonporous; moderately hard; medium bedded; unit is not well exposed, but is highly weathered and leached; grayish orange 10YR7/4 to moderate yellowish brown 10YR5/4, allochems are stained orange brown, weathers to medium to dark gray.
12	3.0'	Dolomite: finely crystalline, saccaroidal; burrowed; 10% to 15% porosity; moderately soft to moderately hard; massive; unit isn't well exposed; light olive gray 5Y6/1, weathering dark gray to black.
13	4.0'	Dolomitic limestone: mixed shell-fragment biomicrite; less than 5% porosity; hard; medium bedded; yellowish gray 5Y8/1 to 5Y7/2, weathers medium to dark gray.
14	6.7'	Dolomite: finely crystalline, saccaroidal; contains scattered leached miliolids; burrowed; wispy horizontal laminae visible in slab; 10% to 15% porosity; yellowish brown iron stains around larger pores; moderately hard; bedding obscured by weathering; mottled, grayish orange 10YR7/4, yellowish gray 5Y7/2, light olive gray 5Y6/1, weathers dark gray to black.
15	1.5'	Dolomitic limestone: mixed shell-fragment biomicrite; contains fine to coarse sand-size allochems; miliolids; dolomitized burrow-fills; approximately 5% porosity; hard; massive; mottled, yellowish gray 5Y7/2 with light olive gray 5Y6/1 burrow-fills, weathers medium to dark gray.
16	11.8'	Dolomite: finely crystalline, saccaroidal; contains leached oyster shell-fragments, *Exogyra* sp.; extensively burrowed; beds in middle of unit have numerous iron-stained, yellowish brown laminations and mottles; 15% to 20% porosity in some beds; moderately hard to hard; medium to thick bedded; mottled, yellowish gray 5Y7/2 to light olive gray 5Y6/1, weathers dark gray to

UNIT	THICK.	DESCRIPTION
		black.
18	30.0'	Dolomite: fine to medium crystalline, sugary; burrowed; 15% to 20% porosity; moderately soft to moderately hard; locally friable; thick bedded (bedding obscured locally by weathering); mottled, grayish orange 10YR7/4 to light olive gray 5Y6/1, weathering dark gray to black.
	18.0'	Covered interval.

Top of Glen Rose Formation

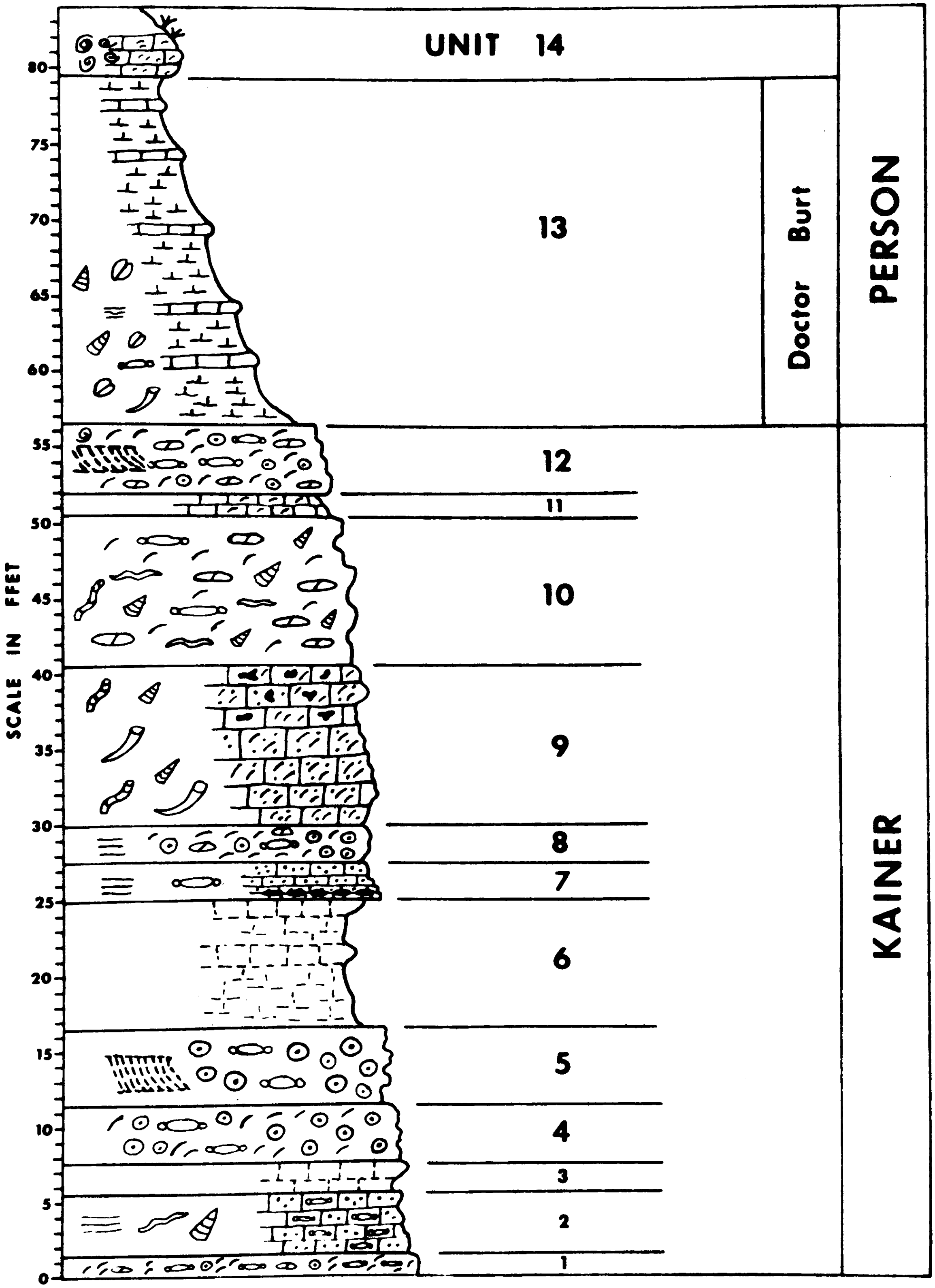


Figure 18. Measured Section Four

Measured Section Four

Location: The section is in the southeastern corner of the quadrangle on the W. J. Marbach Ranch approximately 0.7 miles north of the ranch house and 0.6 miles northeast of Barrett Industries quarry. It was measured in a tributary to Cibolo Creek, starting 1,600 feet west of where the tributary intersects the creek.

UNIT	THICK.	DESCRIPTION
1	1.5'	Limestone: miliolid biosparite; contains a few scattered intraclasts, coated grains, and mollusc shell-fragments; hard; massive; blocky weathering profile; light gray N7, weathering medium gray to greenish gray.
2	4.0'	Limestone: pelletal miliolid biomicrite and miliolid pelmicrite in alternating laminae; contains 20% to 70% silt to medium sand-size, well sorted and rounded allochems; scattered gastropod steinkerns, oyster shell-fragments, rare solitary corals; laminated; approximately 5% porosity; hard; thick bedded; yellowish gray 5Y8/1 and light olive gray 5Y6/1, weathers medium gray to greenish gray.
3	2.0'	Recrystallized limestone: honeycombed; 15% to 20% porosity; hard; medium bedded; medium light gray N6 to yellowish gray 5Y7/2, weathers medium gray to greenish gray.
4	4.0'	Limestone: oösparite; contains mostly medium to coarse sand-size, well sorted and rounded oölites, at least 50% with miliolid nucleii; scattered mollusc shell-fragments; nonporous; hard; thick bedded; karren developed on exposed bedding surfaces; yellowish gray 5Y8/1, weathers medium gray at base to greenish brown near top of unit.
5	5.0'	Limestone: oösparite; contains mostly fine to coarse sand-size, moderately sorted, well rounded oölites, 30% to 40% with miliolid nucleii; cross bedded; 3% to 5% porosity; honeycombed in spots; hard; medium bedded; blocky weathering profile, numerous north-south joints; karren pits on bedding surfaces ½" to 1" in diameter; yellowish

UNIT	THICK.	DESCRIPTION
		gray 5Y8/1 with light olive gray 5Y6/1 mottles, weathers medium gray to greenish gray.
6	8.5'	Recrystallized limestone and caliche: mostly soft, crumbly, punky, pulverulent material with a few moderately hard more resistant layers; nodular; bedding obscured by weathering; tan to medium gray, weathers to light reddish brown or yellowish brown with medium greenish gray harder layers.
7	2.5'	Limestone: pelmicrite; contains very few scattered miliolids; laminated; nonporous; very hard, resistant, breaks with a conchoidal fracture; medium bedded; blocky weathering profile; yellowish gray 5Y7/2 to light olive gray 5Y6/1, weathers light olive gray 5Y6/1 to greenish gray 5GY6/1 to medium light gray N6; a layer of lenticular chert nodules, dark brown to black with light gray to white patinas, occurs 6 inches from base of unit.
8	2.5'	Limestone: oösparite; contains mostly fine to medium sand-size well sorted and rounded oölites; few miliolids and intraclasts up to 2 cm, few mollusc shell-fragments; contains a few 3 or 4 mm thick micrite laminae; approximately 3% to 5% porosity; hard; medium bedded; scattered leached and recrystallized areas; yellowish gray 5Y8/1 to 5Y7/2, weathers medium gray to greenish gray.
9	10.5'	Limestone: pelletal mollusc shell-fragment and whole mollusc biomicrudite; contains 30% to 50% poorly sorted, subangular unoriented allochems; gastropods, caprinid steinkerns, _Chondrodonta_ sp.; burrowed; 1% to 3% porosity; very hard; thick bedded; honeycombed; numerous joints; contains irregular scattered dark brown to black chert nodules in upper 3 feet; yellowish gray 5Y7/2, weathers medium gray to greenish gray with a light pink to light orange tinge.
10	10.0'	Limestone: muddy, fossiliferous intrasparite; contains mostly medium sand to granule-size, poorly sorted, rounded, horizontally oriented allochems; intraclasts up to maximum of 2 cm; numerous small gastropod steinkerns, _Nerinea_

UNIT	THICK.	DESCRIPTION
		sp.?, miliolids, oyster shell-fragments; few burrows; karren pits on bedding surfaces; hard; 1% to 3% porosity; medium to thick bedded; blocky profile; very pale orange 10YR8/2 to yellowish gray 5Y8/1, weathers medium gray.
11	1.5'	Limestone: fossiliferous micrite; nonporous; moderately hard; thin bedded; nodular; yellowish gray 5Y7/2 to dusky yellow 5Y6/4, weathers medium to dark gray.
12	4.5'	Limestone: fossiliferous intrasparite; contains very fine sand to granule-size, poorly sorted to well sorted, rounded, oriented allochems; some beds consist almost entirely of fine sand-size coated grains; intraclasts up to 2 cm; numerous miliolids, mollusc shell-fragments, Toucasia sp.; cross bedded; nonporous; hard; medium bedded; very pale orange 10YR8/2 to yellowish gray 5Y7/2 with light olive gray 5Y6/1 intraclasts, weathers medium gray.

Top of Kainer Formation

UNIT	THICK.	DESCRIPTION
13	23.0'	Argillaceous limestone: interbedded fossiliferous micrite, biomicrite, and dismicrite; contains clam and gastropod steinkerns, few miliolids and ostracods, large caprinid molds in lower 5 feet; thin wispy laminations visible in a few beds; scattered burrows; more resistant beds contain scattered 1 or 2 cm vertical spar-filled fractures; up to 1% glauconite in some samples; nonporous; moderately soft to soft when weathered, moderately hard when fresh; thin to medium bedded, nodular; grayish orange 10YR7/4 to very pale orange 10YR8/2, weathers very light gray N8 to medium light gray N6.

Top of Dr. Burt Member of Person Formation

UNIT	THICK.	DESCRIPTION
14	----	Limestone: whole rudist biomicrudite; Toucasia sp.; slightly honeycombed; hard; thick bedded; weathers medium to dark gray.

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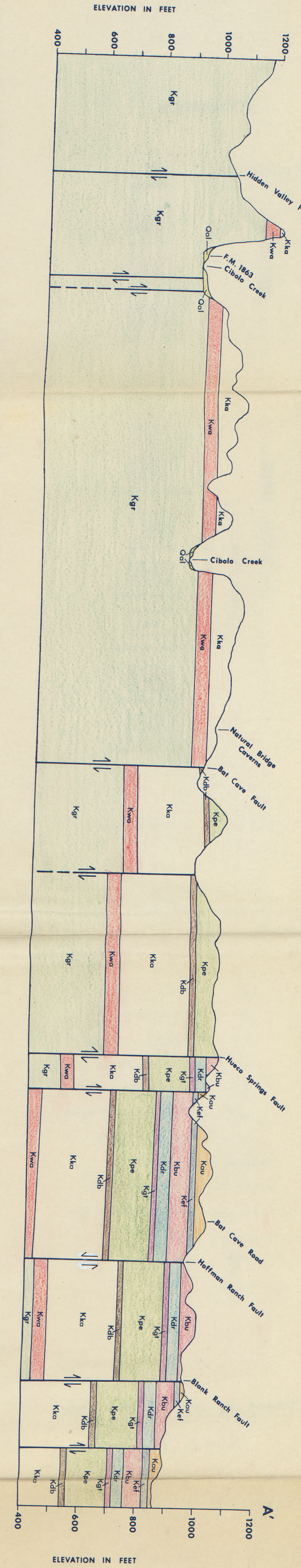
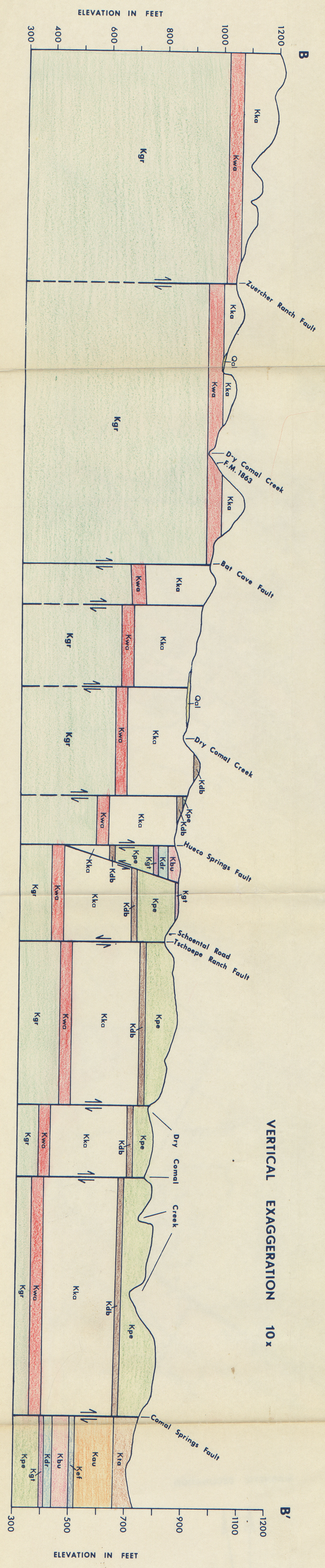
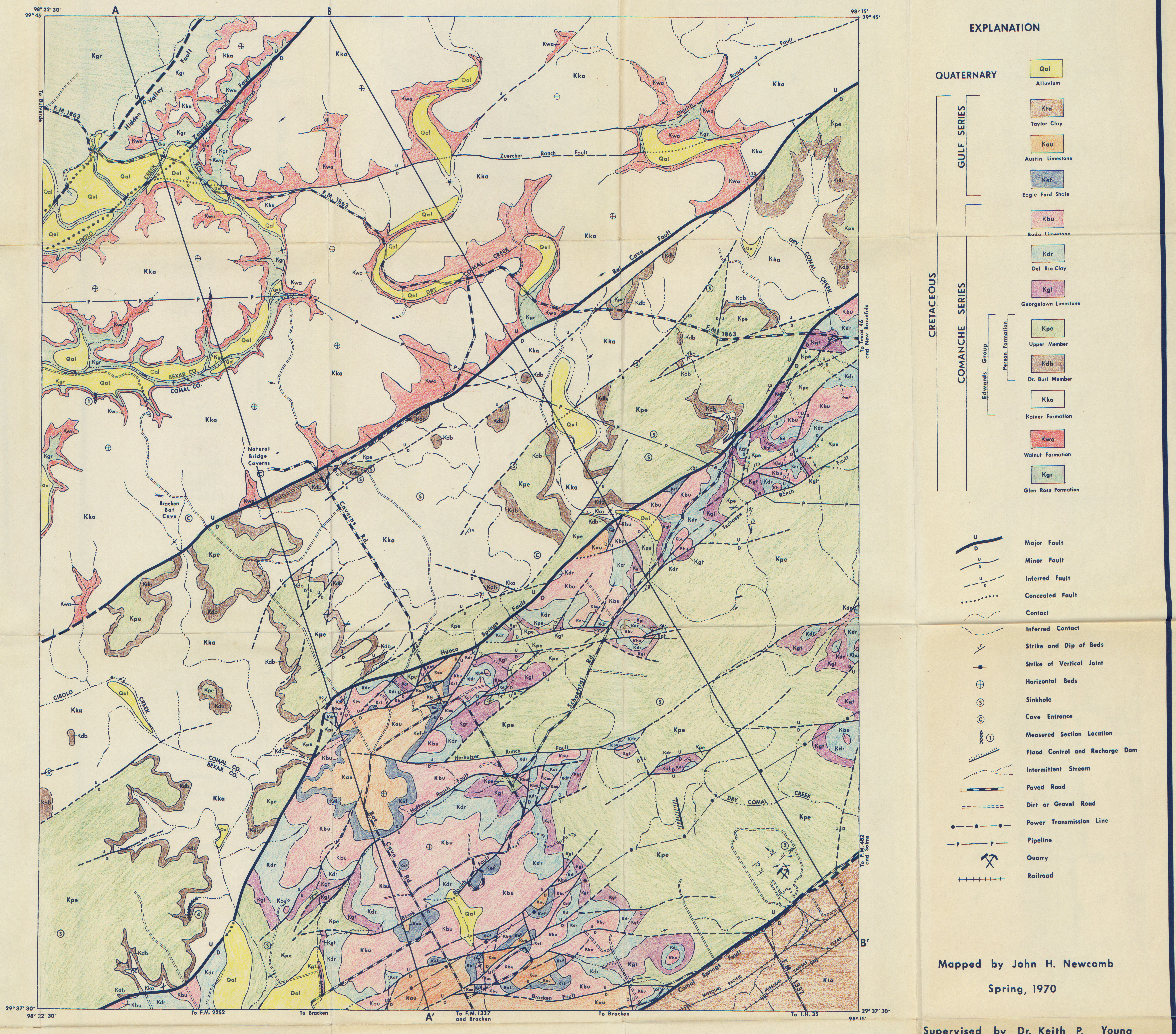
PLATE 1





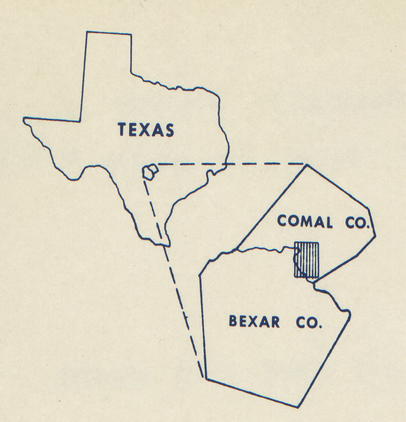


Mapped by John H. Newcomb

Spring, 1970

Supervised by Dr. Keith P. Young

Department of Geological Sciences
The University of Texas at Austin



LOCATION OF MAP AREA

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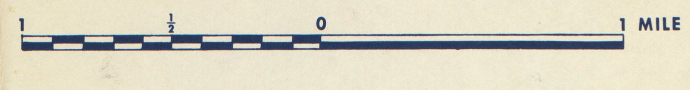

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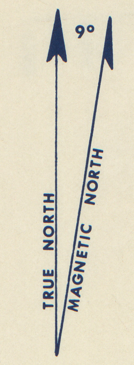

BASE MAP: U.S.G.S. BAT CAVE 7-1/2 MINUTE TOPOGRAPHIC QUADRANGLE

GEOLOGIC MAP AND CROSS SECTIONS OF THE BAT CAVE QUADRANGLE, COMAL AND BEXAR COUNTIES, TEXAS

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